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GUIDELINES FOR IMPROVING EFFICIENCY IN ELEMENTARY SCHOOLS IN WESTERN MASSACHUSETTS: A DATA ENVELOPMENT ANALYSIS APPROACH

A Dissertation Presented

by

MOHAMMAD REZA ZOMORRODIAN

Submitted to the Graduate School of the
University of Massachusetts in Partial Fulfillment
of the requirements for the degree of

DOCTOR OF EDUCATION

May 1990

School of Education

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DEDICATION

This dissertation is dedicated lovingly

to my parents

and

to my wife.

ACKNOWLEDGEMENT

Many talented people contributed to the completion of this project and I wish to offer my deepest gratitude.

I am deeply indebted to Dr. Robert L. Sinclair who started me upon this journey of personal and professional growth. As my Committee Chairperson, my advisor and my mentor since the start of my program, Bob has guided me steadily toward becoming a more sensitive, caring and capable educator.

I gratefully acknowledge the help of Dr. Thomas E. Hutchinson and Dr. Byrd L. Jones who provided guidance, encouragement and assistance throughout the development of this study. To the other member of my committee, Dr. Lawrence M. Seiford, I give special thanks for his patience, expertise and many hours of conversation.

Appreciation is also extended to Dr. Agha Iqbal Ali for sharing the software for DEA which was essential to the completion of this study. Dr. Richard K. Hill, of Advanced Systems in Measurement and Evaluation, Inc., is also gratefully acknowledged for his kind assistance in providing the Massachusetts Educational Assessment Program data.

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Finally, I thank my wife, Toni, who lovingly and patiently stood by me throughout this long journey.

ABSTRACT

GUIDELINES FOR IMPROVING EFFICIENCY IN ELEMENTARY SCHOOLS IN WESTERN MASSACHUSETTS: A DATA ENVELOPMENT ANALYSIS APPROACH

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Concurrent with the public outcry of recent years to improve the quality of America's schools, has come a demand for accountability in public education. This study employs Data Envelopment Analysis (DEA) as a measure of technical efficiency in the allocation of limited resources in eighty-one non-rural public elementary schools in Western Massachusetts.

Three major research questions guided the study:

1. How do the selected elementary schools differ as to the degree of inefficiency when compared with each other?

2. What factors may account for differences in expected achievement among relatively efficient schools?

3. What factors may account for differences in relative efficiency scores?

Data were collected for four outputs representing student achievement and for sixteen inputs representing a

balance of school, student and teaching resources. Preliminary analysis reduced the number of inputs to eight.

DEA results indicated that of 81 schools, 37 (or 46%) were found to be efficiently utilizing their resources and 44 (or 54%) were found to be inefficient to varying degrees. DEA provided for each school a relative efficiency index, an identified peer set of efficient schools, optimal weights assigned to inputs and outputs, and estimates of the augmentations in outputs and/or the reductions in inputs (i.e., slack values) that could be attained if efficiency were to be achieved.

Since the DEA analysis results identified the sources and degree of inefficiency, the factors could be adjusted to remove these inefficiencies and thus the variables which influenced student achievement could be determined; four inputs were found to be significant. Five inputs (representing three areas of resources) were identified as contributing most to differences in relative efficiency scores by being overconsumed, or underutilized, in a significant number of schools.

The study concludes that the strength of DEA lies in its ability to identify empirically-based sources and amounts of inefficiencies in a multiple outputs-multiple inputs setting. Limitations exist primarily in the availability of data for outputs and inputs. Finally, DEA can add significantly to renewal at the school level by providing school decision makers with the tools to make valuable and effective choices.

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CHAPTER I

NATURE OF THE STUDY

Statement of the Problem

Criticism of schools in the United States is not a new phenomenon. However, the criticism of recent years is significant in that the nature and depth of concern may point to a loss of faith in the institution of schooling itself (Goodlad, 1984). John I. Goodlad believes this signals a need to restructure our schools. In A Place Called School, he presents convincing evidence of the need for schools to cultivate their capacity to deal with their own problems. Goodlad's message is that the individual school is the most appropriate place for effective improvement, and he wisely points out that understanding schools is prerequisite to improving them. Knowledge of the ways schools function in general and of the conditions and inner workings of selected schools is crucial to a focused diagnosis and the setting of an agenda for school improvement.

Concurrent with the public outcry to improve the quality of America's schools, has come a demand for accountability in public education, both in terms of expectations for measurable student achievement and with regard to allocation of available resources. Within an environment of rising costs, limited resources and demand for economic efficiency, the State of Massachusetts has set as a top priority the delivery of equal and quality education to all of its students.

Robert L. Sinclair and Ward J. Ghory, in an inquiry into school renewal from the perspective of reaching marginal students, concur with Goodlad that decentralization of administrative control is an essential foundation for reform. The authors note further, "many school systems, however, are reluctant to shift responsibility to the school level, withholding from the principal the authority to make key budgetary and personnel decisions that affect curriculum and instruction" (Sinclair and Ghory, 1987, p.7).

Information that is needed to make decisions of this type in an informed manner is frequently missing, or research methodologies are so deficient that alternative choices can be contrasted in only the most general way (Bessent et al., 1982). One of our key concerns, as educational researchers, should be to provide school people with the knowledge they need to make informed decisions at the building level to set agendas for educational improvement. This study seeks to explore the issue of how this responsibility might be met among schools in Western Massachusetts.

A considerable body of literature documents numerous attempts to identify, by defining an educational production function, the factors which help to produce student learning. A number of the variables which have been identified as influencing student achievement -- including innate student characteristics, socioeconomic background, and peer group experiences -- are factors over which schools have no direct control. The nature of the relationship between student learning and variables over which schools do have control is, therefore, of paramount importance in organizing learning environments.

This study seeks to help educators determine how to organize available resources to maximize student achievement. Until recently, methods of evaluating this process have been fraught with difficulties. This study will focus on the issue of efficiency in the organization of resources in public elementary schools, using Data Envelopment Analysis (DEA) as an efficiency measure. DEA holds tremendous promise as a tool for defining educational production processes in terms of unique conditions in individual schools and should bring greater decision-making capabilities to school principals. Sinclair and Ghory (1987, p. 8) explain: "Within the school the role of the principal is to articulate the mission of quality integrated education in terms of local conditions and to lead teachers and parents in accomplishing this mission with learners."

Purpose of the Study

The purpose of this study is to examine the issue of efficiency in public elementary schools. In particular we will determine the extent of inefficiency for selected non-rural public elementary schools in Western Massachusetts. A method of efficiency measurement will be proposed for analyzing data from the Massachusetts Educational Assessment Program for 1988 to provide a means for answering three major research questions:

1. How do the selected elementary schools differ as to the degree of inefficiency when compared with each other?

2. What factors may account for differences in expected achievement among relatively efficient schools?

3. What factors may account for differences in relative efficiency scores?

Meaning of the Terms

The following meanings are provided for terms which have special relevance for the study. The reader will find them to be a useful aid to understanding the study.

Efficiency Efficiency means technical efficiency, which refers to utilizing available resources in such a way that the maximum feasible output is produced, that is, no alternative organization of resources would yield a larger output.

Outputs, Student Achievements Outputs (student achievements) are defined, within the context of this study, as the academic progress of students as measured by standardized achievement tests. Alternative definitions of outputs as they relate to student achievement and the problems inherent to measuring student achievement as output are discussed in Chapter II.

Inputs Inputs are defined as a resource or factor of production, such as labor skills, or piece of equipment, that is employed in a production process.

Resource Allocation Resource Allocation is defined as the apportionment or utilization of personnel, materials, or monies available to the school.

Regression Analysis Regression Analysis is a set of statistical techniques, the purpose of which is to quantify the relationships between two or more variables. The objective may be to apply the techniques of statistical inference to determine if the variables can be expected to be closely related in the population of items under study. Regression analysis also permits different hypotheses about the forms of the relationship and about the variables which should be included to be tested.

Data Envelopment Analysis Data Envelopment Analysis (DEA) is a methodology for measuring and distinguishing different kinds of efficiencies. It permits one to uncover the degree and sources of inefficiency in a multiple outputs-multiple inputs setting and thus determine the organizational units (schools) operating on the efficient frontier.

Slack Values Slack values represent unnecessary consumption of resources or shortcomings in output achievement. Slack resources may be in the form of time spent on instruction, teacher hours, money, classroom space or any number of such resources.

<u>Return to Scale</u> Returns to scale represent the proportionate increase in output that results from a given proportionate increase in all the inputs employed in the production process. Three possible relationships exist between the increase in inputs and the increase in outputs. For an increase in all inputs by a factor of K:

1. Increasing return to scale: output increases by more than K.
2. Decreasing return to scale: output decreases by less than K.
3. Constant return to scale: output increases by exactly K.

Significance of the Study

Persistent concern about the quality of education in conjunction with rising cost has raised questions about the efficiency of the education sector.

This research will address the issue of efficiency, and the results of the study will provide clear policy prescription to improve the learning environment.

One potentially valuable outcome is the identification of sources of inefficiencies and the estimation of amounts of inefficiencies. Improvements in outputs as well as conservation of resources in the form of reduction in the inputs utilized are evidently of interest as matters of public management and policy. Thus, there is reason to suppose that there is interest in methods for improving the processes of evaluating and controlling both the inputs and the outputs associated with the activities and operation of schools.

This study is significant for several reasons. First, it will identify a peer set of efficient schools (which have similar output and resource levels), to serve as examples for the resource allocation decisions and achievement targets of less efficient schools. Second, the study will provide information on utilization of school resources. Providing information to school decision makers will assist them in the allocation of school resources. Third, the study will provide managerial information on the output augmentation level and the resource conservation levels that will make an inefficient school an efficient one. Fourth, the study is significant because it will identify the important inputs on which school decision makers should focus for educational improvement. Finally, it is hoped that research on school efficiency will assist ongoing efforts to increase student achievement at the local school level and throughout Massachusetts.

Hopefully this study will make some contribution to the understanding of a school production process and its operation, which is vital in attaining educational goals.

Delimitations of the Study

1. The elementary school is used as the unit of analysis for several reasons. First, a number of studies indicate that the pattern of achievement shows a high degree of stability in the early grades (Bowles, 1970). Second, the likelihood of obtaining stable inputs, outputs and efficiency measurements is best offered by elementary schools. Because most elementary school students are likely to attend only one school, their educational experience and academic achievements are influenced only by a single school's environmental factors.

2. The set of input and output measurements for each school must be comprised of non-zero, positive values. There can be no missing values.

3. The study is limited by the input and output measures available for collection and by the sample of schools selected.

4. Output measures for student achievement were selected to reflect school goals. The selected input measures were determined to be significant factors in producing student achievement.

5. The study is limited by the quality of surrogate measures for some inputs (which were chosen to conform to the available data) for which reliability is unknown.

6. The study is designed to include Western Massachusetts elementary schools, therefore any conclusion reached cannot be generalized beyond that population.

CHAPTER II

REVIEW OF THE RELATED RESEARCH

Over the past three decades a considerable amount of research has focused on identifying the relationship between school and non-school factors and students' achievement test scores. This chapter consists of five parts. Part one describes educational production functions; Part two summarizes input and output studies; Part three discusses methods for measuring efficiency; Part four reviews research related to Data Envelopment Analysis; Part five explains limitations of these efficiency methods.

Educational Production Function

In a general sense, production -- in economics -- is the creation of a good or service that has economic value either to consumers or to other producers. Economic production transforms inputs into outputs. Inputs (or "the factors of production") are the resources (i.e., labor, capital, and natural resources) -- either in their original state or as the result of an earlier production process -- that are used to produce goods and services (i.e., economic outputs).

The theory of production is centered around the concept of a production function. It is, essentially, a conceptual tool which helps economists to understand the relationships between inputs and outputs in the production process.

Theory of production asserts that, given qualitatively and quantitatively defined inputs (including specific technological information), we can determine the maximum quantity of output that can be produced from given amounts of various inputs for a given technology. This relationship of maximum output to specific inputs is expressed as the production function in the form of a mathematical relationship.

Thus, the educational production function may be expressed as the following relationship between academic achievement and educational inputs:

Academic Outcomes = f (innate student characteristics, student's family background, peer characteristics, community influences, teacher characteristics, expenditures on instructional materials, teacher salary, teacher-student ratio, ...).

Production of most outputs requires the use of many inputs. Also, many production processes result in more than one output. Nevertheless, while the relationships may appear to be complex, the inputs and outputs, themselves, generally can be specifically defined. This is not the case in the economic analysis of education. Defining educational inputs and outputs is difficult.

The production function in education is, like its counterpart in economics, a mathematical relationship describing how educational resources (inputs) can be transformed into educational outcomes (outputs). As in economic production processes, many educational inputs may be required and multiple outputs may be the result in the "production" of education.

There are, however, some significant differences between the purely economic and the educational production function. This is due, in part, to the very nature of educational inputs and outputs. Many educational inputs are not directly measurable, and there is often no unanimous agreement on what constitutes a unit of educational output, let alone agreement on how to measure it (Cohn, 1979). Furthermore, educational outputs do not exist either to the exclusion, or entirely independently, of other outputs.

These problems underscore the degree of difficulty, and the importance, of defining the educational production function. The process is, first, one of very carefully defining, quantifying and measuring the inputs and the outputs, and second, one of defining the process by which inputs are transformed into outputs.

Educational Inputs[1]

A vast number of inputs, from diverse sources, contribute (both directly and indirectly) to the production of educational outcomes. It should be the goal of the individual who undertakes an analysis of the educational

[1]Information for the following discussions of educational inputs and of educational outputs was obtained from Cohn, 1979, pp. 164-171.

production process to identify as many of those inputs as possible.

This does not mean that every known input will be appropriate to use in every production function formulation. The process of choosing and defining educational inputs is, essentially, a judgmental one. Individuals committed to this difficult process need to remain aware of the range of possible choices so that they can make the best estimation of educational inputs.

In light of their goals, educators wishing to increase the quantity and quality of educational output by means of better resource allocation need to pay particular attention to input factors which can be manipulated within the school environment. These manipulable school factors are, essentially, the only tools available to educators hoping to improve resource allocation by means of practical application of production function analysis.

A brief description of possible educational inputs may be helpful. The reader should, however, be aware that this is not a definitive list of all known educational inputs, but rather an introduction which may inform new consumers of production function research.

School related factors of educational production (i.e., school inputs) include both human and physical resources within the school environment. Human inputs include teachers, administrators and school and administrative support staff. A wide variety of inputs may be derived from these human factors. For example, we must consider not only the quantitative aspects of human input (such as teacher salaries, years of teacher preparation and experience, student-teacher ratio, numbers of support staff such as counselors, special needs teachers, or teacher aids, and years of experience of school administrators, to name a few); we must also examine the qualitative aspects of human inputs, including teachers' talents, enthusiasm, resourcefulness, dedication, productivity, classroom practices, skill in organizing and communicating information, and attitudes toward students and colleagues. We might wish to include, as well, teachers' and administrators' views of their roles and responsibilities, and qualitative aspects of professional communication.

Physical school inputs include building characteristics (such as general physical condition, and architectural design with respect to instructional needs, special facilities for handicapped or special needs students, curricular needs such as library, sports, vocational or arts facilities, social organizational structure, and ease of communication among faculty members and students); quantity and quality of physical equipment (such as audiovisual teaching aids, computers, instructional supplies, library resources, vocational equipment, musical instruments, sports equipment, etc.); and other supporting physical facilities (such as heating and air conditioning, transportation vehicles, playground space, outside sports facilities, etc.).

Of these human and physical school inputs we must consider that some factors work directly, whereas others work indirectly in producing educational outputs. Furthermore, some school inputs are easily manipulated, whereas others are less so or are manipulable within certain limits, and still others are completely non-manipulable given the unique constraints of individual schools. For example, class size may be easily changed by the hiring of additional teachers or, given a fixed number of teaching positions and classrooms, by trade-offs between a smaller class size and a heavier teaching load. Physical school size, on the other hand, may be nonmanipulable in the short run where constraints in budget or physical space preclude the use of portable classrooms but manipulable in the long run when a new school building may be built.

Nonschool (or external) factors may also contribute substantially to educational output. Among these factors are inputs related to student characteristics, home environment, community influences and peer influence.

Nonschool factors, like school factors, may have direct or indirect influence on educational output. For example, parents' level of education and family income and attitudes have been found to have a rather direct effect on educational outcome, whereas community attitudes toward education have generally been thought to have a more indirect effect.

Furthermore, we again have manipulable and nonmanipulable inputs related to external factors. Race, sex, and family size are all nonmanipulable student characteristics. Parent socioeconomic levels or educational attainment are, theoretically, manipulable, but change could be accomplished neither quickly nor easily. The result is that these factors may hold implications for long-run social policy but are not likely to be useful for increasing educational output in the short run.

Identifying educational inputs is, nevertheless, easier than accurately measuring them. Questions arise particularly in relation to inputs of qualitative human factors. For example, how can we accurately measure teacher enthusiasm? What factors might determine a valid scale? Frequently, proxies must be used to represent the real inputs, and proxies seldom satisfactorily track the real factor.

A brief description of educational inputs shows enormous complexities not only of defining and measuring educational inputs, but of defining the entire production function, as well. As we will see, educational outputs are even more difficult to define and measure, as is the process of relating inputs to outputs.

Educational Outputs

In the production function, educational outputs, like inputs, must be very well defined. Again, the researcher should attempt to describe as many relevant outputs as possible and to obtain reliable means by which outputs can be measured.

Problems arise, first, with the definition of educational output. Surely, there are many valid perspectives on what are desirable educational goals and outcomes. Teachers, parents, students, administrators, community members, and members of society at large are all likely to have different priorities for educational outputs.

Furthermore, the question of what outputs should be sought may, in fact, be the wrong one to ask; the more appropriate question (in specific circumstances) may be one of what outputs are actually being produced, or what outputs have taken place over a certain time period.

Secondly, problems arise as to adequate measurement of educational outputs. Many tests have been developed to measure basic skills in learning, but no widely accepted measures have been defined to evaluate the many other kinds of human learning which frequently do take place inside (and outside) schools. Again, we have the problem of choosing proxies to represent measures of actual outputs; and, we must grapple with intercorrelation among varying outputs.

A brief description of possible educational outputs may illuminate the problems with definition and measurement:

1. Measurement of basic verbal and mathematical abilities has been the traditional means of defining educational output in production function studies. Many basic skills tests are available; nevertheless, their degree of accuracy may be compromised by built in cultural bias in favor of some student groups in relation to others or by "coaching" of students in test taking.

2. Measurement of other areas of human knowledge -- for example, the humanities and the social, behavioral, natural, and technological sciences -- has generally <u>not</u> been present in the educational production literature. It is unclear whether this failure has been due to neglect on the part of researchers or to difficulty in designing measurements of these areas of learning; but clearly, this learning is an important part of educational output which needs more attention in the educational input-output research.

3. Other areas of learning which have been neglected include vocational skills, sports, art, and music. In the case of vocational education, market oriented studies have assessed employment opportunities and/or earnings related to vocational education, but no systematic vocational tests of the type developed for basic skills appear in the literature. Since vocational development is an identifiable educational goal, it also deserves more attention in the research. Sports, art and music have similarly been neglected, even though they have important consumption and,

for students who wish to become professional athletes, artists, or musicians, investment benefits.

4. Creativity is another important educational output, both as creative output (a consumption benefit) and as increased creative potential (an investment benefit). Particularly where schools try to foster creativity, these outputs need to be evaluated in relation to the inputs which help to produce them.

5. The inculcation of attitudes is frequently among the educational goals of schools (as cited in many state planning documents); however, they have seldom entered the formalized input-output research. The range of student attitudes that educators hope to influence includes those of self, family, peers, community and society at large. These attitudes frequently include areas of lifestyle, career and educational aspirations, health habits and citizenship, to name only a few. We can see the difficulty that might be encountered in trying to measure these attitudes; nevertheless, psychologists have been successful in measuring some attitudes related to life experiences, and those techniques could be applied to attitudes that comprise educational outputs.

6. Finally, social welfare is also an output of the educational system that is usually neglected in the educational production research. Schools do serve functions such as "babysitting," lessening job competition by retaining older, job-ready youth in school, offering hot

meals, counseling, and health services, and in some cases, providing childcare services for young mothers who are students. These outputs are, certainly, linked to other educational outputs, and their importance to formal analysis should not be ignored.

The reader can see, from this brief outline, that problems of recognizing, defining, and measuring educational outputs make the process difficult. Furthermore, the interrelationship and interdependence of educational outputs add even greater complexity. However, attempts have been made to accomplish the task, and in fact, some progress has been forthcoming in recent years due to more representative proxies of educational outputs and to better techniques of measurement and collection of data.

The Input-Output Process

As we have seen, the first step of the formulation of an educational production function is to quantify (i.e., to define and to measure) the relevant educational inputs and outputs. The second step is to determine specifically how those inputs influence the outputs. In economic terms, this means that we need to determine the mathematical relationship between inputs and outputs; that is, we need to determine the shape of the production function.

It must be noted that the difficulty in this process lies in the fact that there is no single, "unique" production function. Even in purely economic production function formulations, there are innumerable mathematical representations of the (equally plentiful) sets of relationships between inputs and outputs. In the case of education, the complexity of the inputs and outputs, themselves, compounds the complexity of the relationships between educational inputs and outputs.

Thus, we can see that understanding the mathematical relationship between educational inputs and outputs is (like the first step in production function formulation), largely, a judgmental process. The best method available is one of collecting empirical data and of using computer-assisted statistical techniques (i.e., curve fitting methods) to estimate the shape of the production function, thus, giving us the significant variables of input that influence our chosen output. This process is one of trial and error, carried out by knowledgeable researchers, who are guided by the relevant economic theorems, and by knowledge of mathematical and statistical techniques.

Clearly, we can never be sure that the final choice of production function is a completely accurate description of the input-output relationship. This is a "best estimation" situation. Furthermore, this fact points to one of the caveats of production function formulation. That is, conclusions derived from the estimated production function should <u>not</u> be applied to input levels beyond the range of the sample observations (from the collected empirical data). Simply put, the shape of the production function at unobserved input levels may, in fact, be very different from what is assumed or inferred from the data, and the result can be a grossly distorted picture of input-output relationships.

Input-Output Studies

The general formulation that most studies have used to estimate the relationship between inputs and outputs is represented by the following equation (Levin 1974).

(1) $Y_i(t) = F \{X_{1i}(t), X_{2i}(t), X_{3i}(t), X_{4i}(t), X_{5i}(t)\}$

where the subscript i refers to the ith student; (t) refers to an input that is cumulative to time t.

$Y_i(t)$ = a vector of educational outputs for the ith student at time t.

$X_{1i}(t)$ = a vector of individual and family background characteristics cumulative to time t.

$X_{2i}(t)$ = a vector of school inputs relevant to the ith student cumulative to time t.

$X_{3i}(t)$ = a vector of peer or fellow student characteristics cumulative to time t.

$X_{4i}(t)$ = a vector of other external influences (the community, for example) relevant to the ith student cumulative to time t.

$X_{5i}(t)$ = a vector of initial or innate endowments of the ith student at time t.

The first large scale study of this type was undertaken for the Educational Testing Service by William G. Mollenkopf and S. Donald Melville in 1956. A sample of more than 200 schools for 9th and 12th grade students was chosen. The study used correlation techniques between 7 dependent variables and 34 independent variables. For dependent variables students' achievement tests were used, and for independent variables, school characteristics, community characteristics, and socioeconomic background of students were selected. The researchers found that library and supply expenditures were correlated with student achievement. Other inputs such as specialized school support personnel, class size, and student-teacher ratio had limited influence on student achievement.

The next major input-output study, The New York Quality Measurement Project, was sponsored by the State of New York and completed by Samuel M. Goodman in 1959. The study used a sample of 70,000 pupils from 7th and 11th grade public schools in New York State. Using correlation techniques, Goodman identified the following inputs to be positively correlated to student performance: expenditure for instruction, teacher experience, number of school support personnel and classroom atmosphere.

James Thomas (1962) applied Project TALENT data in the first major input-output study to use regression techniques (Cohn, 1975). The study used a sample of 206 schools nationwide and, from a list of 27 input variables, found starting teacher salary, teacher experience, and number of books in school library to be positively related to student achievement.

Benson and his associates (1965) used a sample of 5th grade students in 249 California school districts to identify the variables which were significant contributors to student achievement. The researchers found a significant positive relationship between teacher salary and student achievement.

The largest, most comprehensive and controversial study to date was published in 1966 by James S. Coleman and his associates. Known as the Coleman Report and entitled Equality of Educational Opportunity, this study used a random sample of over 3,300 elementary and high schools. The data were collected through questionnaires which were sent to teachers, principals, and superintendents. The study used correlation matrices to identify the correlation between 93 independent variables and 10 dependent variables. From these independent variables, 60 variables were chosen and used for the study. The regression analysis purported that school related inputs assert little influence on educational outputs as compared to non-school factors. The following independent variables were significant contributors in production function: reading materials in the home, possessions in the home, parents' education, number of siblings, parents' educational desires, parents' interest, integrity of the home, and urbanism of background.

Coleman's methodology and conclusions have been criticized by many scholars -- most notably by Samuel Bowles (1969) and Henry M. Levin (1968, 1970).

> The Coleman report has been criticized along three basic axes. First, there is uncertainty as to whether the measurements used are sufficient for the task involved. Second, the handling of the data is thought by some to have been less than precise. Perhaps most damning, however, is the fact that many contend the manner by which the regression technique was used in effect stacked the cards against any strong showing by school factors.
>
> Basically, this latter argument is that step-wise multiple regression requires the statistical assumption of independence of variables. Where such independence is not present (i.e., multicollinearity is present), the first variable to be entered (in this case non-school factors) will appear most potent. (Cohn et al. 1975, p.37)

Furthermore, the Coleman data have been reworked by many scholars, including James W. Guthrie (1971), Eric Hanushek (1968, 1972), and Cohn (1979). A comprehensive reanalysis of Coleman's data was undertaken for the U.S. Office of Education by George W. Mayeske and his colleagues. The result was a deeper analysis of the data, published in three reports during 1972 and 1973 (Cohn, 1979).

Although still hotly debated, the Coleman and Mayeske reports stand as a benchmark in educational assessment research. The Coleman Report attracted public attention to the relationship and the importance of school inputs and student achievement (Hanushek, 1979). The public furor that the report generated stimulated further research into issues of school effectiveness; and input-output analysis, which was at the time an obscure and specialized field, came to prominence as a methodology for public policy research (Cohn et al. 1975).

Keisling (1967), in his study related to the New York Quality Measurement Project, used school districts in New York and found a significant negative relationship between the cognitive output measures and student-teacher ratio as well as expenditures for books and supplies.

Burkhead, Fox and Holland (1967) studied a sample of 39 Chicago schools, 22 Atlanta schools and 177 schools from Project TALENT. The researchers found a significant positive relationship between family income, teacher experience, teacher salary, and output measures of student reading and verbal skills.

Katzman (1968) used 10 independent and 5 dependent variables; data were collected from 56 Boston elementary schools. Using multiple regression techniques, Katzman found a positive relationship between cultural advantage, size of school areas, and reading test scores. He also found a negative relationship between teacher experience, student-staff ratio, and reading test scores.

Cohn (1968), in a study of 377 Iowa high schools identifying economies of scale in education and efficient districts' school size, found a negative relationship between the output (test scores) and two inputs (number of teacher's college credit hours, and number of teaching assignments). He also found a significant positive relationship between output and teacher salary (Cohn, 1975).

Raymond (1968) used a sample of 5,000 freshmen at West Virginia University for a period of three years. He selected college grade-average and American College Test scores as the output measures. Regression was used with 15 independent variables. He found a positive significant relationship between output measures and teacher salary.

In 1968 Hanushek used a portion of the data from the Coleman Report to study the effect of school and nonschool inputs on Blacks and Whites. Verbal ability and mathematical achievement were output measures. He used separate regressions for the Black and White samples. Hanushek found teacher experience and teacher verbal ability were positive and significant in both samples.

Levin's (1968) analysis of the Coleman data examined cost effectiveness of schools, utilizing the same sample of urban schools studied by Hanushek. Levin found teacher experience and teacher's verbal ability to be significant for verbal achievement by students. Although he indicated that more experienced teachers were twice as effective per dollar expenditure with Black students as opposed to White students, Levin concluded that the schools could achieve greater cost effectiveness by increasing the numbers of teachers with greater verbal ability and by reducing emphasis on teachers' previous experience.

Bowles (1969) used a portion of data from Project TALENT and the Coleman Report for Black students. He used two different samples, one for 12th grade Black males from Project TALENT data, the second sample for 5th grade Black students from the Coleman Report. The output measures were reading, mathematics, and composite achievement scores. He found teachers with graduate school training (positive) and ability grouping practices (negative) were significant input measures for the 12th grade students. For the second sample, he found the following input measures to be significant: teacher verbal ability, guidance services, science laboratory facilities and the number of days school was in session.

Fox (1969) used a simultaneous equation model for his study. He added a different set of school inputs for 39 Chicago schools in his sample. The input measures which he found to be significant were the total number of teacher man years, total amount of expenditures for text and library books, and the number of student hours spent in vocational classes.

Kiesling (1969) collected data from 97 school districts in New York. He used two different samples, rural and non-rural districts. The output measure was the Iowa Test of Basic Skills. He found no significant relationship between school inputs and student achievement for rural schools. For the non-rural sample, he found a negative relationship between output and pupil-teacher ratio, as well as for expenditures per pupil for books and supplies.

Hanushek (1970) used data for over 1,000 students from a single school district in California. Hanushek compared Mexican-American students with White students. The sample was divided into subsets depending on the student's father's occupation (manual or nonmanual). Two dependent and 21 independent variables were selected. For White students (manual subset) he found a positive relationship between output (SAT scores) and teacher verbal ability and a negative relationship between output and teacher experience. For the nonmanual subset, teacher experience had a positive relationship with student achievement. The subset of Mexican-Americans did not show any relationship between teacher characteristics and student achievement.

In 1970, Levin analyzed a sample of 36 schools in a large Eastern city from the Coleman Report data. He applied two-stage least squares regressions and found that only teacher experience was positive and significant. When he used ordinary least squares (OLS) he identified seven independent variables which were significant. These variables are as follows: student's attitude (positive), grade aspiration (positive), age (negative), family size (negative), possessions (positive), father's education (positive), teacher experience (positive), and teacher's undergraduate institution (positive).

Michelson (1970) applied Coleman Report data on 597 White and 458 Black six-graders in a large Eastern city who had attended only one school. He used 33 independent variables and 5 dependent variables. For the sample of White students, he found a significant positive relationship between student verbal scores (output) and teacher experience, and teacher verbal ability. For the sample of Black students, he found no significant relationship. His suggestion was that particular types of students need different types of teachers and perhaps special teaching methods.

Kiesling (1970) analyzed data from 86 school districts in New York State. He used 17 independent and 3 dependent variables. He found four significant input variables: mother's education level (negative), teacher certification level (positive), teacher experience (positive), and administrative expenditure per pupil (positive).

Kiesling (1971) utilized an input-output approach for 42 schools in California. The Stanford Reading Test was selected as output measure. The only significant input measure that he identified was the amount of instruction time that the individual student spent with a teacher.

Guthrie and his associates (1971) analyzed Coleman data for the State of Michigan. The sample was stratified by socioeconomic status. They found a few significant school input variables related to student achievement. The most significant input measures were teacher verbal ability, experience, and job satisfaction.

Averch and Kiesling (1972) used data from Project TALENT for 746 public high schools. Simultaneous equation models were applied to identify the relationship between student achievement and a set of inputs. Socioeconomic index, male teacher's average salary and number of tracks (i.e., ability grouping) were positively related to achievement. The class size had a negative impact on student achievement.

Brown (1972) analyzed data for 520 school districts in Michigan using two-stage least squares regressions. Socioeconomic status, number of students, region of the state, and community type were found to be negatively significant to output.

Perl (1973) used a random sample from Project TALENT at the student level for his study. He chose verbal ability and abstract reasoning as independent variables. He found a positive relationship between output measures and the following input measures: father's occupation, mean income of students, teacher's specialization, number of books in library and expenditure per pupil.

Bidwell and Kasarda (1975) analyzed data for 104 Colorado School districts. They found a negative correlation between student achievement and ratio of administrators to teachers as well as pupil-teacher ratio. They also found a positive relationship between reading scores (one of the output measures) and the percent of staff with a master's degree or higher. However, they did not find the same relationship with mathematic scores.

Cohn, Millman, and Chew (1975) applied regression models for 53 Pennsylvania high schools. They used 12 outputs and over 50 inputs. Among these input measures, teacher salary showed a positive correlation to the output measures. Input measures which were negatively related to the outputs were the following: teaching load, hours of use of paraprofessionals, and curriculum units available per grade level.

Muranae's (1975) study was based on 875 Black 2nd and 3rd grade students in Connecticut. He found a significant positive relationship between student achievement and teacher experience. He also found that male teachers were more effective compared with female teachers. He suggested that more experienced, Black male teachers should be hired for inner city schools in Connecticut.

Sledge (1975) analyzed a sample of more than 100 Illinois public school districts. The reading achievement test scores were used for the output measure. Pupil-teacher ratio and geographic setting (i.e., urban, suburban, rural) were found to be related to the output.

The Winkler (1975) study was designed to identify the effect of the socioeconomic mix of a peer group upon student achievement. Winkler selected 388 Black students and 385 White students from one urban California school district.

He found teacher salary and teacher college prestige were significant for both Black and White students. For non-school input measures, the percentage of the peer group from a low socioeconomic background was negatively significant for Black six-grade students. The study did not find any relationship between output measures and non-school inputs for the White students.

Brown (1976) utilized data for 183 school districts in Georgia. He found expenditure per pupil for instruction to be the significant input measure.

Summers and Wolfe (1977) studied Philadelphia public schools. They used one output and 59 input variables. Three input variables which were positively related to the output measure were: teacher's college rating, teacher's experience, and percentage of high achievers. Six input variables were negatively related to student achievement. These input measures were the following: unexcused absences, lateness, class size, school size, percentage of low achievers, and disruptive incidents.

Dunkelberger and Soderberg (1980) used the California Achievement Test as an output measure and seven input variables for 127 Alabama school districts (45 metropolitan and 82 rural). They found that the geographic location (city or county) was significantly related to the output. Other input measures which were significant for both city and rural school locations were expenditure per student (positive), pupil-teacher ratio (negative) and average daily attendance (positive in rural schools).

Freeman and Hatley (1981) utilized the Missouri Basic Essential Skills Test (BEST) as an output measure in their input-output study. They found no relationship between output measures and school related inputs.

Sebold and Dato (1981), in their study of California schools, chose 100 districts and applied multiple regression techniques to identify the relationships between outputs and inputs. They divided the school expenditure into subgroups such as support service expenditure, auxiliary programs, general education instructional expenditures, and special education instructional expenditures. They also used students' and family characteristics for more inputs. They concluded that general education instructional support expenditures was the most significant input measure.

In 1981 Wendling and Cohen presented their study of more than 1,000 public schools in New York. For non-rural schools they found teacher experience, teacher education, pupil-teacher ratio, operating expenditures, and instructional expenditures were positively related to student achievement. They also found rural schools' achievement correlated less with socioeconomic factors. The study showed that rural schools with less expenditure per student had higher achievement test scores.

Summers and Raivetz (1982) utilized data for 1,828 fourth grade students from 25 public elementary schools in

Philadelphia. A set of school and non-school variables were included in their model. They found teacher characteristics to be the most significant input measures.

In 1983 Guth studied more than 9,000 students from North Carolina schools. Analysis was conducted at the school level. Out of 15 input measures Guth found that teacher's level of education and teacher certification were positively related to student achievement.

Webb, Metos, and Metha (1984) used the California Achievement Test as an output measure for 212 Arizona School districts. They found teacher experience to be positively related to the output. Pupil-teacher ratio was found to be negatively related to student achievement.

Turner, Camilli, Kroc, and Hoover (1986) studied 102 Colorado school districts. For the elementary schools, they found teacher education and district size to be significant. For the high schools, teacher salary was a significant input measure.

Eberts and Stone (1988) utilized data from a sample of over 14,000 fourth grade elementary school students in the United States. The purpose of the study was to show the relationship between student achievement and characteristics of principals. The mathematics achievement test scores were selected for an output measure. For the input measures, characteristics of schools, principals, teachers, and students were chosen. The results showed that principals make a difference to student achievement.

A summary of selected input-output studies is shown in Appendix A. The findings of these studies show significant input variables in three general areas: the school environment -- class size, student attendance, expenditures per pupil; the home environment -- family background and socioeconomic status; and the teaching environment -- teacher experience, salary, and verbal ability.

The selection of the studies in this section serves two purposes: first, it will demonstrate some of the historical foundations of production function studies in education; second, documenting these common findings serves to support the selection of input variables that will be used in our study.

Measures of Efficiency

Three methods are commonly used to measure efficiency: ratio analysis, multiple regression and data envelopment analysis.

Ratio Analysis

The relationship between a single output and a single input is represented by a ratio at a specific point in time. Concepts such as pupils taught per teacher and average cost per pupil can be represented by these ratios.

For each decision making unit (DMU) such as a school, a ratio of each output to each input is computed. The DMU with the highest ratio is considered to be the most efficient unit. Many ratio studies undertaken in the field of education can be found in Lindsay (1982), and Walberg (1982).

Multiple Regression

The second method to measure efficiency is multiple regression. Multiple regression analysis can describe the relationship between the level of a _single_ output and various levels of inputs. The least squares technique is used to estimate the relationship between the level of output and inputs. The difference between actual output and the estimated output is defined as residuals. Relative efficiency is measured by the residuals. DMUs with positive residuals are considered to be relatively efficient and the ones with negative residuals are relatively inefficient (Silkman, 1986).

Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a relatively new methodology that was designed specifically to examine efficiency of not-for-profit institutions such as schools in _multiple_ output-_multiple_ input settings. The theory and methodology was developed and refined by Charnes, Cooper and Rhodes (1978, 1981) and has been applied to a nationwide sample of schools in Project Follow Through.

A brief description of DEA is as follows:

> Data Envelopment Analysis (DEA) is itself a basic concept. It can be applied to empirical data via different types of models to obtain estimates of the relative efficiency of Decision Making Units (DMUs). DEA uses observed or reported values of multiple outputs and inputs for each DMU and mathematically selects a subset of efficient DMUs

> -- those which are most like the DMU being evaluated (in terms of input and output mixes) -- to effect its performance evaluations. Each DMU is individually evaluated and the amounts and sources of its inefficiencies are estimated and identified. (Ahn, 1988 p. 286)

Data Envelopment Analysis Studies

Bessent and Bessent (1980) have applied DEA to fifty-five urban elementary schools from one district with 60,000 pupils in Texas. Two output measures (reading and mathematics achievement scores) and 13 input measures were used. Among 13 input measures, four inputs were selected from neighborhood and home conditions. Two inputs were previous reading and mathematics tests scores. School related inputs were number of professional staff per 100 pupils, and total instructional expenditures per pupil. Five other input measures were from school organizational climate (job satisfaction, social interaction among teachers, teacher's motivation, principal's cooperation with teachers, and individualized teaching methods). Among 55 schools analyzed, 31 efficient and 24 inefficient schools were found. A diagnosis for the three most inefficient schools was presented. The analysis of slack values and opportunity costs and the reallocation of slack resources among schools was also presented.

In the initial study which presented DEA, Charnes, Cooper and Rhodes (1981) utilized data from 49 schools with over 3,200 students of Program Follow Through (a large scale social experiment in public education) and over 1,200 students from 215 schools of non-Follow Through. The researchers applied DEA to both samples. Efficiency indices and diagnostic information for inefficient schools were presented.

Splitek (1981) used DEA for 497 elementary schools in Texas; 28% were efficient and 72% were inefficient. For inefficient schools he identified three areas of inefficiency: first, financial resources as measured by instructional expenditures; second, the student resources as measured by the percent of non-title I students in the school; and finally, teaching resources as measured by the level of experience that teachers bring to schools. He concluded that:

> The fact that several broad resource areas are represented and are underutilized resources, suggests that either management of the schools is generally ineffective, or that the resources are interrelated and influence each other. The latter means that the level of use of one resource affects the levels of other resources. (Splitek, 1981 p. 139)

Bessent, Bessent, Kennington, and Reagan (1982) in applying DEA to 167 elementary schools in the Houston Independent School District found 78 schools to be inefficiently using their resources as compared to 89 efficient schools. The mean scores for grades three and six from the Iowa Test of Basic Skills were used as the two output measures for each school. Five input measures related to students' characteristics and seven input measures of school resources were chosen for this study. The study showed that the most inefficient schools have had adequate resources but resources were not fully utilized.

Bessent, Bessent, Charnes, Cooper and Thorogood (1983) used DEA to measure the efficiency of 22 programs in San Antonio College in Texas; of the 22 programs, 8 were efficient and 14 inefficient. The researchers provided samples of how DEA may be used in planning and decision making, augmenting existing programs, starting new programs, and combining existing programs.

In a recent study by Jesson, Mayston, and Smith (1987) DEA has been applied to 96 schools in England. The researchers selected two output measures (the percentage of students passing five or more '0' level courses, and the percentage of students passing three or more '0' level courses). The first output measure was the reflection of success rate for higher ability groups and the second output measure was for more basic levels of achievement. Four input measures were the percentage of students from high socioeconomic backgrounds, the percentage of students not from one parent families, the percentage of students born in the U.K., Ireland, U.S.A or Old Commonwealth, and expenditures per pupil. The analysis could be used to highlight the extent of the improvements in educational outputs that are possible for each individual school within its existing resources, and possible expenditure savings.

Limitations of Efficiency Methods

1. Ratio analysis does not directly take into account the interactions which may occur with changes in the remaining variables and which may be associated with the ratio under consideration. Also, the ratio analysis does not account for multiple input-output relationships. Therefore, it is possible to derive conflicting and ambiguous results. A partial solution to the above limitations can be provided by the applications of multiple regression analysis.

2. Regression studies measure efficiency relative to average rather than best performance. While regression handles multiple inputs, it fails to capture multiple output relationships. Also, regression techniques require prior specification of the functional form relating inputs to outputs. These limitations can be overcome by applying Data Envelopment Analysis.

3. The limitations of Data Envelopment Analysis are less severe than other techniques. First, as the number of input and output variables increases (relative to the number of DMUs), the ability to discriminate between DMUs declines. So when we are dealing with a small sample of DMUs, we should limit the number of inputs and outputs used in DEA. Second, DEA is based on technical efficiency. This means a DMU which is perfectly efficient cannot produce any additional unit of output from its existing inputs, or cannot reduce its inputs and still produce the same level of

output. DEA is not based on price efficiency of a DMU. DEA cannot determine if the output is produced by least-cost technologies.

In the literature on regression studies on education the major focus has been to identify important factors to maximize student achievements. What has emerged from these studies is a set of policy recommendations for school improvement. In the literature on DEA studies, the major emphasis has been to determine the degree of relative efficiency of schools. What has emerged from these studies is a set of policy recommendations to improve school efficiency.

Chapter Summary

In part one of Chapter II, Review of the Related Research, an understanding of the complex relationships between educational resources and student learning was discussed in terms of the identification of an educational production function. This process was defined as, largely, a judgmental one involving, first, the collection of empirical data (to measure educational outputs and inputs) and, second, the use of computer-assisted statistical techniques (i.e., curve fitting methods) to estimate the shape of the production function, thus, giving us the significant variables of input that influence our chosen outputs.

It was noted that the complexity of the inputs and outputs, themselves, compounds the complexity of the relationships between (and among) educational inputs and outputs, and that the process is further complicated by the fact that there is no single, "unique" production function. Thus, conclusions derived from the estimated production function should not be applied to input levels beyond the range of the sample observations since the shape of the production function at unobserved input levels may be very different from what is assumed or inferred from the data.

It was also noted that educators wishing to increase the quality and quantity of educational output by means of better resource allocation need to pay particular attention to input factors which can be manipulated within the school environment.

Part two of this chapter presented a summary of input-output studies, which were first conducted in 1956 and continue into the present. The purpose of the review was twofold: first, to present the historical foundations of production function studies in education; second, to document common findings to support the selection of input variables that are used in this study. The findings of these studies, which are summarized in Appendix A, showed significant input variables in three general areas: the school environment, the home environment, and the teaching environment.

Part three of Chapter II described the three methods that are commonly used to measure efficiency: ratio analysis, multiple regression analysis, and data envelopment analysis. Ratio analysis represents the relationship between a single output and a single input at a specific point in time for an individual DMU (decision making unit). Multiple regression analysis describes the relationship between a level of output and various levels of inputs. Data envelopment analysis (DEA), which was designed specifically to examine efficiency of not-for-profit institutions such as schools, is the only viable method of evaluating relationships among multiple outputs and inputs.

Part four of the chapter summarized the data envelopment analysis studies, the first conducted in 1979. These studies generally provided an efficiency evaluation of individual schools and included the estimated augmentations in outputs and/or reductions in inputs that could be attained if efficiency were to be achieved.

Part five of the chapter suggested that the limitations of data envelopment analysis are less severe than other techniques of estimating efficiency. What has emerged from past DEA studies is a set of policy recommendations to improve school efficiency.

CHAPTER III

DESIGN OF THE STUDY

The purpose of this chapter is to outline the procedures that are involved in the sample selection, the instrument selection, and the data collection, and the methods that are used to analyze the data.

To operationalize the study, the following procedures are outlined:

Sample

All non-rural public elementary schools having a fourth grade (totaling 186 schools) in Western Massachusetts (i.e., roughly the western half of the state, including Berkshire, Franklin, Hampden, Hampshire, and the western part of Worcester counties) were selected to participate in this study. Schools which serve only special constituencies, such as special education students or gifted students, were excluded from the study.

A questionnaire was designed to collect the data, deemed necessary to answer the three research questions, that was unobtainable from other sources. Of the 186 schools to which the questionnaire was sent, 90 schools responded. Eighty-one of those ninety responses provided complete and usable information. (The names of the 81 schools participating in the study appear in Appendix B.)

Instrumentation

The data that are used in this study were obtained from the following sources:

1. The data on student test scores, students' pre-school attendance, students' home environment, percentage of non-minority students and percentage of students not eligible for free or reduced price lunch were obtained from The Massachusetts Educational Assessment Program, 1988 Statewide Summary (Massachusetts Department of Education, November 1988).

The Massachusetts Educational Assessment Program (MEAP) is one of two statewide testing programs mandated by the state in 1985. The assessment program's stated purpose is twofold: to furnish information to improve curriculum and instruction in Massachusetts schools, and to provide reliable results for comparisons at the school, district, and state levels.

Test questions from the National Assessment of Educational Progress (NAEP) are incorporated within the MEAP tests to provide a basis for national comparison. Other questions are developed specifically to assess objectives defined by the Massachusetts Board of Education in 1987. Test objectives are revised for each round of testing.

The MEAP tests are administered biennially to three grade levels in major subject areas. In addition to the subject area tests, all participating students, teachers and principals complete questionnaires designed to elicit data about their backgrounds, classroom practices, attitudes toward learning, and other factors that have been shown to relate to educational achievement. The second statewide assessment was administered to students in grades four, eight and twelve in April of 1988. A total of 52,216 students at the fourth grade level (i.e., ninety percent of fourth grade students in Massachusetts) completed the MEAP tests in the subject areas of reading, mathematics, science, and social studies. School, district and state results were released in November of 1988. From these results the data that is specified above was drawn for this study.

2. The data on school expenditures per student and total operating costs per student were obtained from the Dialog Information Retrieval Service of the Educational Directory Database. The Educational Directory is produced by Market Data Retrieval, Inc. The Directory provides a listing of every school, school district, and library (public and college) in the United States. Each record contains economic and demographic information, including enrollment and current budgetary information. Records are updated yearly during July to September.

3. The data reflecting teacher-student ratios and teacher characteristics, including total years of experience, years of experience at the current school, salary, and level of education, were collected from questionnaires sent to each participating school due to the

lack of published data on these variables. (Cover letter and Questionnaire appear in Appendix C.)

Measurements

The data were collected on selected inputs and outputs.

Outputs

The products of schools' educational processes are used in all production function studies. Also, in studies which use DEA as a tool, student achievement test scores are frequently used as measures of schools' output. The output measures that are used in this study are: means of student scores on the Massachusetts Educational Assessment Program tests. These tests reflect a variety of possible educational goals as defined by the Massachusetts Board of Education. Of the set of goals adopted by the Board in 1987, those goals that are specifically addressed by the MEAP tests include the following:

a. The development of communication skills (including the ability to think clearly and critically).

b. The understanding of citizenship in a democratic society (including the fostering of individual commitment to exercise the rights and responsibilities of citizenship).

c. The understanding of history and the humanities (including knowledge of our multicultural heritage).

d. The understanding of mathematics and the sciences (including the fostering of exploration and discovery).

e. The development of a capacity and desire for lifelong learning (including not only a recognition of the necessity of lifelong learning, but also an appreciation of learning as an opportunity for growth and enrichment).

The goal of the assessment -- to provide aggregated results at the school and district levels -- guides test development, administration, and reporting decisions. A brief description of the assessment tests is presented in a Massachusetts Department of Education publication:

> They are not designed to give information about individual students; they are designed to give information about the effectiveness of the curriculum. They do not measure what is taught at a particular grade level or is commonly taught among districts, but they cover as much as possible of the subject area domains that students might be expected to learn up to grade level tests. To accomplish this purpose, their content must be much broader than that of standardized achievement tests, encompassing the many different kinds of knowledge and thinking processes that reflect the content area. ("Using the School Report," Massachusetts Department of Education, November 1988, p.1)

Test objectives are revised by school and district personnel for each round of testing. Once objectives are defined, committees representing each curriculum area review test items for each grade level and select those they believe to be most appropriate to Massachusetts students. An equity concerns committee reviews the tests to ensure that they are fair and relevant to students from all ethnic, racial and cultural backgrounds.

The relative emphasis placed on topics within each subject area is determined by a curriculum survey sent to all schools throughout the state. In addition to the multiple-choice questions traditionally used in educational assessments, the 1988 MEAP tests included several open-ended (short answer) questions in each subject, which were designed to examine students' ability to apply knowledge and understanding in different contexts. Approximately eight percent of the fourth grade students completed an open-ended section of the test.

Test administration is accomplished through a technique known as "matrix sampling." Because the program seeks only aggregate school and district scores, each student completes only a sample of test questions in each subject. In any school, many students are tested using the same set of questions, thereby producing valid and reliable test scores for the school as a whole. The total number of test questions in the content areas at the fourth grade level are presented in Table 3.1.

Table 3.1

Massachusetts Educational Assessment Program
Cognitive Tests: Grade 4

Content Area	No. of Test Questions
Reading	151
Mathematics	230
Science	230
Social Studies	240
Total	851

The MEAP tests are given in individual classrooms and are administered in most cases by classroom teachers who have attended test administration workshops. All fourth grade students complete a practice test, student questionnaire, and the four-session cognitive test. Each of the four test sessions cover one subject (i.e., reading, mathematics, science, or social studies). Nevertheless, at grade four, there are twelve different forms of the test booklet with subjects arranged in different order, so that students in one classroom work at different subjects during any one test session.

School and district reports include (in addition to other data) scores for each subject, broken down by subskills and objectives. In order to obtain school level data for the purpose of this study, means of the numbers of objectives mastered for each of the four fourth grade subtests, reading, mathematics, science, and social studies, were used. For every content area and subskill area, the range of possible scores is 1000 to 1600. The content areas for each subtest are as follows:

1. Reading
   - vocabulary
   - literal comprehension
   - inferential comprehension
   - study skills
2. Mathematics
   - numbers/numeration
   - operations
   - variables/relations
   - measurement/geometry
   - problem solving skills
   - probability/statistics
3. Science
   - scientific inquiry
   - life science
   - earth/space science
   - physical science
4. Social Studies
   - historical environment
   - political environment
   - physical environment
   - economic environment
   - sociocultural environment

- process skills
- clarifying, evaluating, using information

Inputs

Inputs to the educational processes take many forms. The inputs most frequently used (from the input-output studies listed in Appendix A) are the starting point in selecting input measures for this study. The field of possible inputs includes measures from several different categories: the school environment, student and family background.

The school related input measures include student-teacher ratio, and per student expenditures on text books and instructional materials. Teacher characteristics are also used as an input measurement and include teacher education, teacher experience and teacher salary. For student and family background we utilize information about the percentage of students who are not eligible for free or reduced price lunch and the percentage of non-minority students. The following list outlines the specific input measures to be used in this study:

Input Measures

1. Percentage of students who attended preschool education.
2. Number of times per month that students discuss schoolwork with family members.

3. Number of pages per day that students read at school.
4. Number of hours per day that students watch television.
5. Number of hours per day that students spend doing homework.
6. Number of field trips per year in which students participate.
7. Percentage of students who are not eligible for free or reduced price lunches.
8. Teacher-student ratio.
9. Teacher's total number of years experience.
10. Teacher's number of years experience at current school.
11. Teacher's level of education.
12. Teacher's salary.
13. School's per student expenditure on textbooks.
14. School's per student expenditure on other instructional materials (not including textbooks).
15. School's per student total operating cost.
16. Percentage of non-minority students.

Data Analysis

In the first step of analysis, the four outputs and sixteen inputs are defined and measured. The output measures are: mean scores on reading, mathematics, science, and social studies cognitive tests produced by the

Massachusetts Educational Assessment Program for fourth grade students in 1988. The output measures are listed in Table 3.2, with the abbreviations (code) which will represent the outputs in later graphical figures, and the unit of measurement.

Table 3.2

Output Measures Used in this Study

Output Description	Code	Unit of Measurement
1. Average Reading Test Score	Read	1000-1600
2. Average Math Test Score	Math	1000-1600
3. Average Science Test Score	Science	1000-1600
4. Average Social Studies Test Score	Social	1000-1600

The input measures are calculated for each school as follows:

1. Preschool education. The number of fourth grade students who attended preschool, nursery school or day care before kindergarten is divided by the total number of fourth grade students, and is then multiplied by 100 to arrive at the percentage of students who attended preschool education.

2. Student activity index. This index is computed using inputs numbers two through six in the previous list of sixteen inputs. The objective of constructing such an index is to represent student activity in aggregate terms. The collected data on inputs numbers two through six are based on multiple responses. A weight range of one to four is

assigned to each response of each input, thereby creating an index for each of the five inputs. The five indices are then summed to produce a unique number to represent the student activity index as input measure.

3. Percentage of students who are not eligible for free or reduced price lunch. The number of fourth grade students who are not eligible for free or reduced price lunch is divided by the total number of fourth grade students, and is then multiplied by 100 to arrive at the percentage.

4. Teacher-student ratio. The total number of fourth grade teachers is divided by the total number of fourth grade students, and is then multiplied by 100.

5. Average total years of teachers' experience for fourth grade. The total years of experience for all fourth grade teachers are summed, and then divided by the number of fourth grade teachers to arrive at the average.

6. Average years of teaching experience at the current school for fourth grade teachers. The total years of experience <u>at the current school</u> for fourth grade teachers are summed, and then divided by the number of fourth grade teachers to arrive at the average.

7. Teachers' level of education. The number of fourth grade teachers who have Master's degrees or higher are summed, and then divided by the number of fourth grade teachers to arrive at the average.

8. Average salary for fourth grade teachers. Salaries of all fourth grade teachers are summed, and then divided by the number of fourth grade teachers to arrive at the average salary.

9. Per student expenditure on all instructional materials. Dollar amounts for textbooks and for all other instructional materials are added together. Per student expenditure is calculated as the average dollar amount of all instructional materials purchased per student.

10. Total operating cost per student. This variable is calculated as the dollar amount of the school's total operating costs per student.

11. Percentage of non-minority students. The number of fourth grade non-minority students is divided by the total number of fourth grade students, and is then multiplied by 100 to arrive at the percentage.

A summary of the eleven inputs defined above is presented in Table 3.3. Included in the table are the abbreviations (code) which will represent the inputs in later graphical figures and the unit of measurement for each input. The data for all outputs and inputs investigated in this study appear in Appendix D.

Table 3.3

Input Measures Used in this Study

Input Description	Code	Unit of Measurement
1. Percentage of students who attended preschool education	PRESCH	Percentage
2. Student activity index	S.A.I.	Assigned weight
3. Percentage of students who are not eligible for free or reduced price lunches	NOFREEL	Percentage
4. Teacher-student ratio	TRATIO	Ratio
5. Teacher's total number of years experience	TOTEXP	Years
6. Teacher's number of years experience at current school	CUREXP	Years
7. Teacher's level of education	DEGREE	Percentage
8. Teacher's salary	SALARY	Dollar
9. Per student expenditure on all instructional materials	EXPENDIT	Dollar
10. School's per student total operating cost	TOTCOST	Dollar
11. Percentage of non-minority students	NONMIN	Percentage

✓ In the second step of analysis, the data is analyzed using DEA. This is a relatively new technique that has not been extensively explored in the education field. In this

DEA study we define efficiency as maximum output production in relation to the distribution of inputs among all schools. We calculate an efficiency index for each school, and also calculate slack values for the outputs and inputs of the inefficient schools. The mathematical programming formulation of our particular DEA model is described in Appendix E.

Earlier attempts in applying DEA have been based on the assumption of constant return to scale (an equal percentage change in inputs leads to the same percentage change in outputs). We relax the assumption of constant returns to scale and allow for increasing or decreasing returns to scale. The Banker, Charnes and Cooper (BCC) Model of DEA is used to analyze the data.

Thus, in step two, multiple DEA analyses are performed on the set of all chosen outputs and inputs and also on subsets of the inputs. The reason for such an attempt is to determine a parsimonious set of inputs which produces consistent efficiency scores for all schools. Thus, we run DEA on different sets of inputs (e.g., different sets of five inputs, different sets of six inputs, etc.).

Of these differently sized subsets of inputs, a set of eight inputs is chosen. The eight selected inputs are:

1. Percentage of students who are not eligible for free or reduced price lunch (proxy for student's family income).
2. Percentage of non-minority students.

3. Student activity index.

4. Teacher-student ratio.

5. Teachers' average total years of experience.

6. Teachers' level of education.

7. Teachers' average salary.

8. Per student expenditures on instructional materials.

These inputs represent a balance in terms of selecting variables to represent students' home environments, social and economic status, and school related factors.

In the third and final step, DEA (employing the four outputs and the eight selected inputs) is applied to the analysis of data to answer the three research questions.

<u>Research Questions</u>

<u>Research Question #1</u>: How do the selected elementary schools differ as to the degree of inefficiency when compared with each other?

The input and output data are used to calculate efficiency indices for each school in the study. The proportion of efficient and inefficient schools is then determined. After separating the schools into two groups according to their efficiency indices, descriptive statistics are calculated for each group. T tests are also used to examine the differences between the input and output measures for the two groups.

Research Question #2: What factors may account for differences in expected achievement (output) among relatively efficient schools?

DEA allows us to adjust the factor of inefficiency. This projection of inefficient schools onto the efficient frontier makes all schools relatively efficient. Thus, any differences in expected achievement are not complicated by interaction with inefficiency effects.

Research Question #3: What factors may account for differences in relative efficiency scores?

DEA provides slack values in addition to the efficiency indices. Slack values will show any additional reduction in specific input measures that should be achieved for the schools to operate as efficiently as the most efficient schools, and the improvement in output that could be achieved at the reduced level of input measures. These slack values are the differences between the measured values of outputs and inputs and the values needed for efficiency.

This information provided by DEA may help educators in finding strategies for feasible improvement. It is our hope that this analysis can be used to highlight the extent of possible improvement in educational outputs for each individual school with its existing resources.

Chapter Summary

Chapter III, Design of the Study, has outlined the procedures that were involved in the sample selection, the instrument selection, the data collection, and the data analysis.

Eighty-one non-rural public elementary schools (having a fourth grade) in Western Massachusetts participated in this study. Data were collected from the Massachusetts Educational Assessment Program (MEAP) 1988 Statewide Summary, from the Dialog Information Retrieval Service of the Educational Directory Database, and from questionnaires distributed to each of the 81 schools.

Data were collected on selected outputs and inputs. Outputs were the means of student scores on the 1988 MEAP tests. Input selection was guided by the inputs most frequently used in the educational research literature. Sixteen inputs were chosen for this study.

In step one of the analysis, four outputs and sixteen inputs were defined and measured. Calculations were made for converting the raw data to usable form for the DEA program. Some of the data were aggregated, resulting in a reduction from sixteen to eleven inputs.

In step two of the analysis, multiple DEA runs were performed on many combinations of the four outputs and eleven inputs in an effort to identify a set of inputs which produce consistent efficiency scores for all schools. A set of eight inputs was chosen.

In step three of the analysis, DEA was applied to the four outputs and eight selected inputs to answer three major research questions. The results of the analysis are discussed in detail in Chapter IV, Analysis of the Data.

CHAPTER IV

ANALYSIS OF THE DATA

This study uses Data Envelopment Analysis as a method of efficiency measurement to determine the extent of inefficiency for elementary schools in Western Massachusetts. Analysis of the results of the DEA model proceeds in three phases, each phase corresponding to a major research question guiding the study. Phase one answers the question: How do the selected elementary schools differ as to the degree of inefficiency when compared with each other? Phase two answers the question: What factors may account for differences in expected achievement (output) among relatively efficient schools? Phase three answers the question: What factors may account for differences in relative efficiency scores?

Research Question #1: How do the selected elementary schools differ as to the degree of inefficiency when compared with each other?

Data Envelopment Analysis calculates an efficiency index for each school. An efficiency index (Iota) of one indicates that the school is efficient. An index of less than one indicates that the school is relatively less efficient, or inefficient.

In Chapter III (Design of the Study) we determined that four outputs and eight selected inputs used in DEA will produce the most consistent efficiency scores for all schools. The results of this selected set of outputs and inputs in DEA show that of the 81 schools, 37 are efficient (46%) and 44 are inefficient (54%) to varying degrees.

Table 4.1 shows the efficiency indices for all of the 81 schools in the study. The range of indices and the frequency and percentage of schools for each index are indicated. This information is also presented graphically in Figure 4.1.

In Table 4.2, the data from Table 4.1 is summarized. The efficiency indices are arranged into six classes to form a frequency and percentage distribution. Tables 4.1 and 4.2 show that 68% of the schools are at or above the efficiency index of .95 and that 32% of the schools are below the .95 index. Although DEA identifies 46% of the schools as efficient, some schools with an efficiency index of .98 or higher are very nearly efficient.

Table 4.1

Frequency and Cumulative Percent of Efficiency Indices (IOTA)

Value	Frequency	Cumulative Frequency	Percent	Cumulative Percent
0.797390	1	1	1.2	1.2
0.805480	1	2	1.2	2.5
0.843580	1	3	1.2	3.7
0.861060	1	4	1.2	4.9
0.863160	1	5	1.2	6.2
0.864320	1	6	1.2	7.4
0.865130	1	7	1.2	8.6
0.867260	1	8	1.2	9.9
0.869210	1	9	1.2	11.1
0.877740	1	10	1.2	12.3
0.881540	1	11	1.2	13.6
0.888700	1	12	1.2	14:8
0.908450	1	13	1.2	16.0
0.909090	1	14	1.2	17.3
0.915320	1	15	1.2	18.5
0.916740	1	16	1.2	19.8
0.919450	1	17	1.2	21.0
0.933570	1	18	1.2	22.2
0.935240	1	19	1.2	23.5
0.938860	1	20	1.2	24.7
0.940660	1	21	1.2	25.9
0.942920	1	22	1.2	27.2
0.944110	1	23	1.2	28.4
0.946950	1	24	1.2	29.6
0.948220	1	25	1.2	30.9
0.948300	1	26	1.2	32.1
0.950140	1	27	1.2	33.3
0.951220	1	28	1.2	34.6
0.954020	1	29	1.2	35.8
0.954030	1	30	1.2	37.0
0.957480	1	31	1.2	38.3
0.962850	1	32	1.2	39.5
0.965350	1	33	1.2	40.7
0.966390	1	34	1.2	42.0
0.972810	1	35	1.2	43.2
0.978190	1	36	1.2	44.4
0.978470	1	37	1.2	45.7
0.981370	1	38	1.2	46.9
0.982600	1	39	1.2	48.1
0.987330	1	40	1.2	49.4
0.988660	1	41	1.2	50.6
0.991570	1	42	1.2	51.9
0.994790	1	43	1.2	53.1
0.996810	1	44	1.2	54.3
1.00000	37	81	45.7	100.0
TOTAL	81	81	100.0	100.0

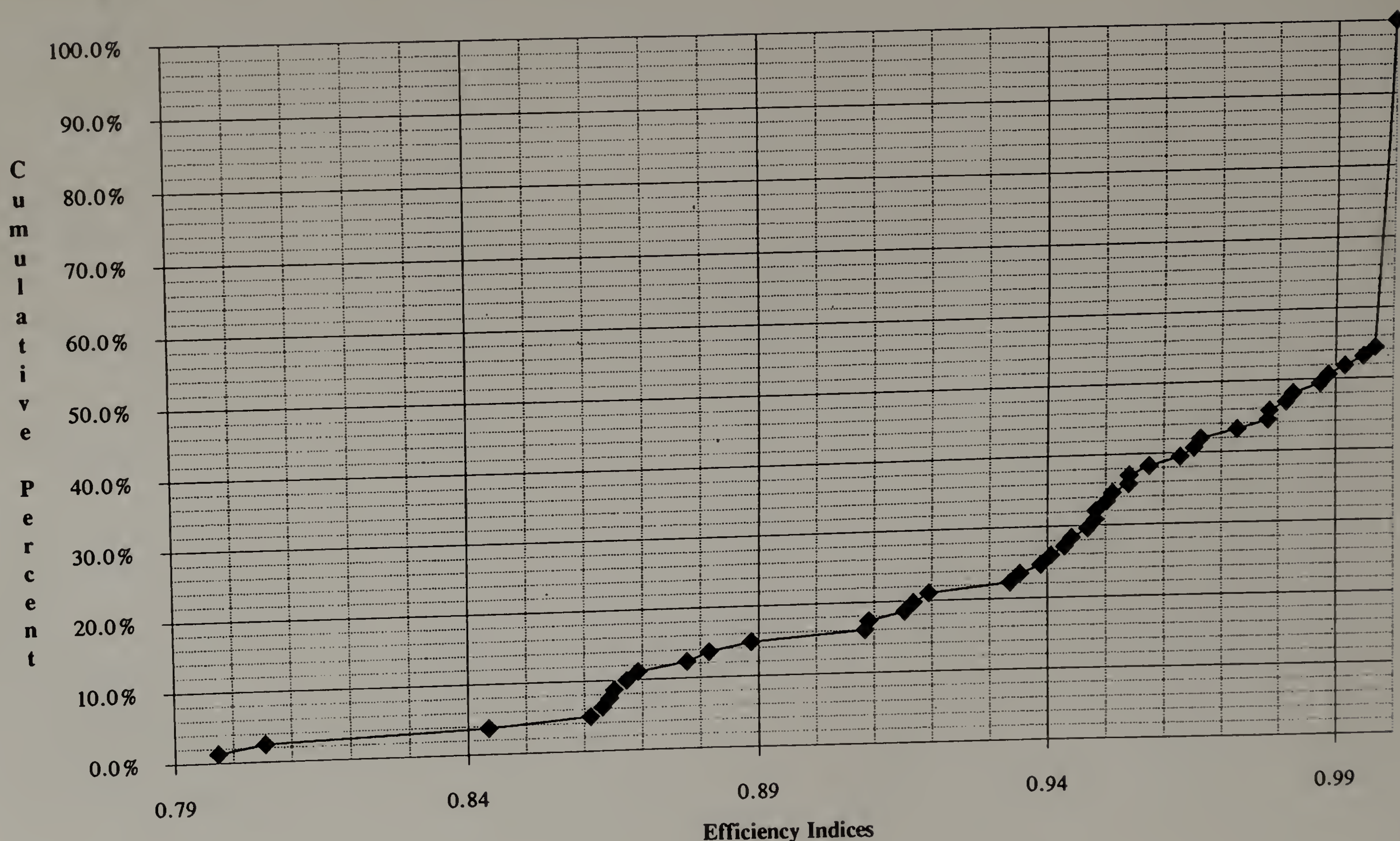


Figure 4.1
Cumulative Percentage of Efficiency Indices

Table 4.2

Frequency and Percentage Distribution of Efficiency Indices

Efficiency Index	Number of Schools	Percentage
1	37	45.7
.95 < 1	18	22.2
.90 < .95	14	17.3
.85 < .90	9	11.1
.80 < .85	2	2.5
Below .80	1	1.2

In order to determine what accounts for differences in degree of efficiency, the 81 schools were split into two groups based on the efficiency index calculated by DEA for each school. Schools with an efficiency index of one (i.e., efficient schools) comprise one group. Schools with an efficiency index of less than one (i.e., inefficient schools) comprise the other group.

Statistical tests were applied to determine whether differences existed between the output and input measures of the two groups. First an F-test was computed to test for the equality of the variances. Then, to compare the differences between the two groups, the t-test based on equal variances and an approximate t-test based on unequal variances were employed.

The results of the statistical tests are shown in Tables 4.3 and 4.4. Table 4.3 depicts the results of the tests on the output measures of each group of efficient or inefficient schools. The results indicate no significant differences between output measures of the two groups.

Table 4.3

Statistics for a Difference in Output for Efficient and Inefficient Schools

Output Measures	Efficient and Inefficient	Number of Schools	Mean	Standard Deviation	F	t*
Reading test score	Efficient	37	1296.2	99.9	1.79	1.01
	Inefficient	44	1276.1	74.6		
Math test score	Efficient	37	1272.7	91.4	1.88	-.16
	Inefficient	44	1275.7	66.6		
Science test score	Efficient	37	1283.5	98.5	2.17	.26
	Inefficient	44	1278.6	66.9		
Social studies test score	Efficient	37	1281.6	96.7	1.78	.19
	Inefficient	44	1278	72.4		

*All t values are based on unequal variances.

Note: A non-parametric test was performed to account for a non-normality assumption. The results of this test confirm the information presented in Table 4.3

Table 4.4 shows the results of the statistical tests for the input measures. Results of the t-test indicate that, among the eight inputs used, five are significantly different at the .05 level. These inputs are: percentage of non-minority students, average total years of teachers' experience, teachers' level of education, average salary for fourth grade teachers, and per student expenditures on instructional materials. The other three inputs -- percentage of students not eligible for free or reduced price lunch, student activity index, and teacher-student ratio -- show no significant differences. These findings suggest there is a difference between efficient and inefficient schools in terms of some of the input measures.

<u>Research Question #2: What factors may account for differences in expected achievement (output) among relatively efficient schools?</u>

Data Envelopment Analysis classified 37 schools as efficient and 44 schools as inefficient. In order to identify the factors which affect student achievement (output), we must adjust for the factor of inefficiency. The data generated by a DEA analysis can be applied to the inefficient schools to accomplish this objective.

Table 4.4

Statistics for a Difference in Input Measures for Efficient and Inefficient Schools

Input Measures	Efficient and Inefficient	Number of Schools	Mean	Standard Deviation	F	t*
NOFREEL	Efficient	37	63.0	29.4	2.30	-1.06
	Inefficient	44	77.2	19.4		
S.A.I.	Efficient	37	13.0	1.41	1.29*	-.44
	Inefficient	44	13.13	1.24		
NONMIN	Efficient	37	77.3	21.6	3.93	-3.31**
	Inefficient	44	90.2	10.9		
TRATIO	Efficient	37	4.12	.744	1.16*	-1.36
	Inefficient	44	4.33	.690		
TOTEXP	Efficient	37	16.51	7.17	1.49*	-2.33**
	Inefficient	44	19.95	5.88		
DEGREE	Efficient	37	143.8	40.9	1.74	-2.70**
	Inefficient	44	165.8	31.0		
SALARY	Efficient	37	28762	4136	2.37	-3.09**
	Inefficient	44	31207	2686		
EXPENDIT	Efficient	37	87.8	18.8	.49	-2.87**
	Inefficient	44	102.4	26.8		

* equal variances
** 5% significance

DEA identifies for each inefficient school the resource levels educators must use and the test scores students must achieve for the school to become efficient. When the original data for an inefficient school is adjusted to these optimal levels, the factor of inefficiency is eliminated.

After the inefficient schools are projected onto the efficient frontier, multiple regression analysis of the 81 (now) efficient schools is used to determine what factors may account for changes in expected achievement. The multiple regression analysis is run separately on each output -- average reading test score, average mathematics test score, average science test score, and average social studies test score -- using the same set of eight selected inputs. Results of the analysis are shown in Table 4.5.

The regression result for the reading test output indicates that six inputs account for 75% of variability in the average reading test score. Among those six inputs, four inputs are positive and significant: percentage of students not eligible for free or reduced price lunch, percentage of non-minority students, teacher-student ratio, and average salary for fourth grade teachers. Two inputs, the student activity index and per student expenditure on instructional materials, are not statistically significant.

Table 4.5

Summary of the Regression Analysis

Input / Output	Constant	NO-FREEL	S.A.I.	NONMIN	TRATIO	SALARY	EX-PENDIT	F	R^2
Average Reading Test Score	777.25 (12.37)	1.38 (3.66)	7.38 (1.70)	2.10 (3.96)	20.48 (2.39)	.01 (3.49)	-.6 (-1.58)	41.57	.75
Average Math Test Score	900.38 (13.17)	1.69 (4.10)	-4.99 (-1.05)	.86 (1.49)	28.22 (3.01)	.01 (3.68)	-.27 (-.64)	25.21	.65
Average Science Test Score	781.22 (15.88)	2.22 (7.48)	1.44 (.42)	.78 (1.86)	25.4 (3.63)	.01 (4.94)	.16 (.53)	68.36	.84
Avg. Special Studies Test Score	765.51 (13.0)	1.57 (4.43)	5.16 (1.27)	1.64 (3.28)	24.26 (3.0)	.01 (4.16)	-.51 (-1.42)	45.01	.77

The value in parenthesis shows the t value.
The level of significance is .05.
The two inputs "average total years of teachers'experience" and "teachers' level of education" were dropped due to high correlation with the other inputs.

The regression result for the second output indicates that the same six inputs account for 65% of variability in the average mathematics test score. Among the six inputs, three inputs -- percentage of students not eligible for free or reduced price lunch, teacher-student ratio, and average salary for fourth grade teachers -- are positive and significant.

In the third regression analysis, results indicate that the same six inputs account for 84% of variability in the average science test score. The significant input variables are: percentage of students not eligible for free or reduced price lunch, teacher-student ratio, and average salary for fourth grade teachers.

In the fourth and final regression analysis, the same six inputs account for 77% of variability in the average social studies test score. Among the six inputs, four are positive and significant: percentage of students not eligible for free or reduced price lunch, percentage of non-minority students, teacher-student ratio, and average salary for fourth grade teachers. Two other inputs, the student activity index and per student expenditure on instructional materials, are not significant.

In short, the regression results indicate that four factors -- the percentage of students not eligible for free or reduced price lunch, the percentage of non-minority students, the teacher-student ratio, and the average salary of fourth grade teachers -- may contribute to differences in expected student achievement among relatively efficient schools.

Research Question #3: What factors may account for differences in relative efficiency scores?

In answering Research Question #3, we first present a broader picture of efficient and inefficient groups. We then present a detailed discussion of some individual efficient and inefficient schools. Finally, we provide some suggestions for how to improve the efficiency rating of a selected inefficient school.

Slack Values

In addition to the efficiency index, Data Envelopment Analysis also provides information on slack values and relative weights for each input and output. Slack values represent the additional adjustment in resource consumption levels for our eight selected inputs that is necessary to achieve efficiency. The extent to which the input factors are identified by DEA as contributing to differences in relative efficiency scores is the degree to which those resources are being underutilized, or overconsumed.

The degree to which each of a schools' resources (inputs) is being overconsumed is indicated by the efficiency level and the slack value for each input. Table 4.6 presents descriptive statistics for the slack values for our 44 inefficient schools.

Table 4.6

Descriptive Statistics for Slack Values

Input	Frequency	Percentage of Schools
NOFREEL	18	40.91
S.A.I.	19	43.18
NONMIN	30	68.18
TRATIO	18	40.91
TOTEXP	40	90.91
DEGREE	29	65.91
SALARY	27	61.36
EXPENDIT	25	56.82

As Table 4.6 indicates, of our eight selected input measures, five appear in more than half of the 44 inefficient schools. Slack in the utilization of teachers' experience is found in approximately 91% of the inefficient schools; slack in the percentage of non-minority students is found in approximately 68% of the inefficient schools; slack in the level of teachers' education exists in approximately 66% of the inefficient schools; slack in the teachers' average salary exists in approximately 61% of the inefficient schools; and, slack in the per student expenditure on instructional materials is found in approximately 57% of the inefficient schools.

These figures imply that the overconsumption of resources occurs most frequently in the factors of teachers' experience, percentage of non-minority students, level of teachers' education, teachers' average salary, and per student expenditure on instructional materials. Over-consumption of resources occurs less frequently in the factors of percentage of students eligible for free or reduced price lunch, the student activity index, and teacher-student ratio.

Since our focus is upon inputs that schools can change or adjust, the most distinctive pattern seen from these data is that the resource of teachers' experience does not seem to be used in the inefficient schools as effectively as in the efficient schools. The other important input which is being used unproductively in the inefficient schools is the resource of teachers' salary. These schools are not purchasing the kind of instruction needed to produce higher output.

Analysis of Output Weights

As noted earlier, DEA also provides information on relative weights for each output and input. In the case of schools' outputs, DEA seeks to maximize the total (virtual) output by assigning the most weight to the school's best level of output (i.e., the best relative to other schools' average assessment test scores). This makes sense when we remember that efficiency equals the greatest possible output produced from the least possible input. The weights assigned to each of our four outputs produced by each of the 81 schools reflect the relative level of production of that output (as shown graphically in Figures 4.2 through 4.5). Thus, the higher the weight assigned to the output measure, the larger amount of that output is being "virtually" produced by the school; and, the lower the weight assigned to the output measure, the smaller the amount of that output is being "virtually" produced by the school. For example, Figure 4.2 shows that school #63 has been assigned the highest possible weight for its production of average reading test score, while school #17 has been assigned a very low weight for its production of average reading test score. Figure 4.3, however, shows that the reverse situation is true for schools #17 and #63 in the production of average mathematics test score.

Figure 4.6 shows graphically the distribution and the overall comparison of the four output weights among all 81 schools in our study.

Figure 4.7 shows the range, including the average, of the weights assigned to each of the four outputs for the total 81 schools. The wider the range of assigned weights, the greater is the difference in output assessment from school to school. For example the weights assigned to the science test output have a significantly wider range compared to the other three outputs. This indicates that some schools produce very high science test scores, that their curriculum is most probably designed to place more emphasis on this particular output, and that they, therefore, assign greater importance to it. At the other extreme, there are schools within our sample of 81 which produce very low science scores on the assessment tests, and the weight assigned to science output for these schools is very low.

Analysis of Input Weights

DEA assigns weights to inputs in a manner that is consistent with its goal of maximizing output. Thus, the smaller the relative amount of input that is being used to produce a given level of output, the greater is the weight assigned to that input. Figure 4.8 depicts a graphical summary of the relative weights assigned to all eight inputs for all of the 81 schools in our sample. Two inputs, the teacher-student ratio and the student activity index, have a significantly greater range of assigned weight, with the other six inputs bunched in the lower range of assigned weight. Figure 4.9 therefore enlarges the scale to show a more accurate picture of the weights assigned to the six inputs. Figure 4.10 summarizes the weight range for each input for the total 81 schools. The implication for those inputs with a significantly greater range of assigned weight -- most notably the teacher-student ratio and the student activity index -- is that some schools appear to be using these inputs quite effectively while other schools appear to being using the same inputs at a very low level of effectiveness. The graphical representation of weights assigned to the eight inputs for each individual school appear in Appendix F.

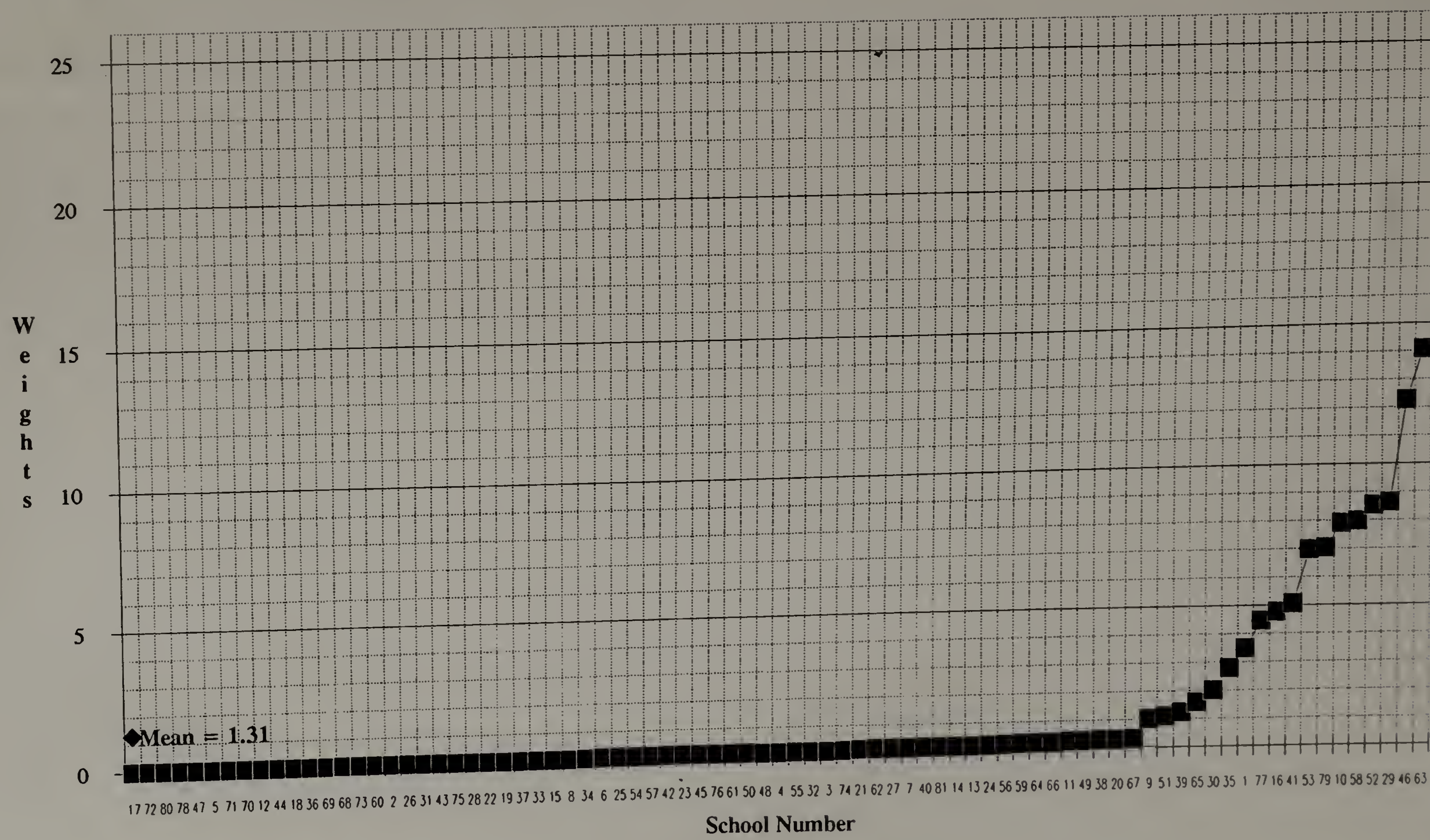


Figure 4.2
Assigned Weights: Reading Assessment

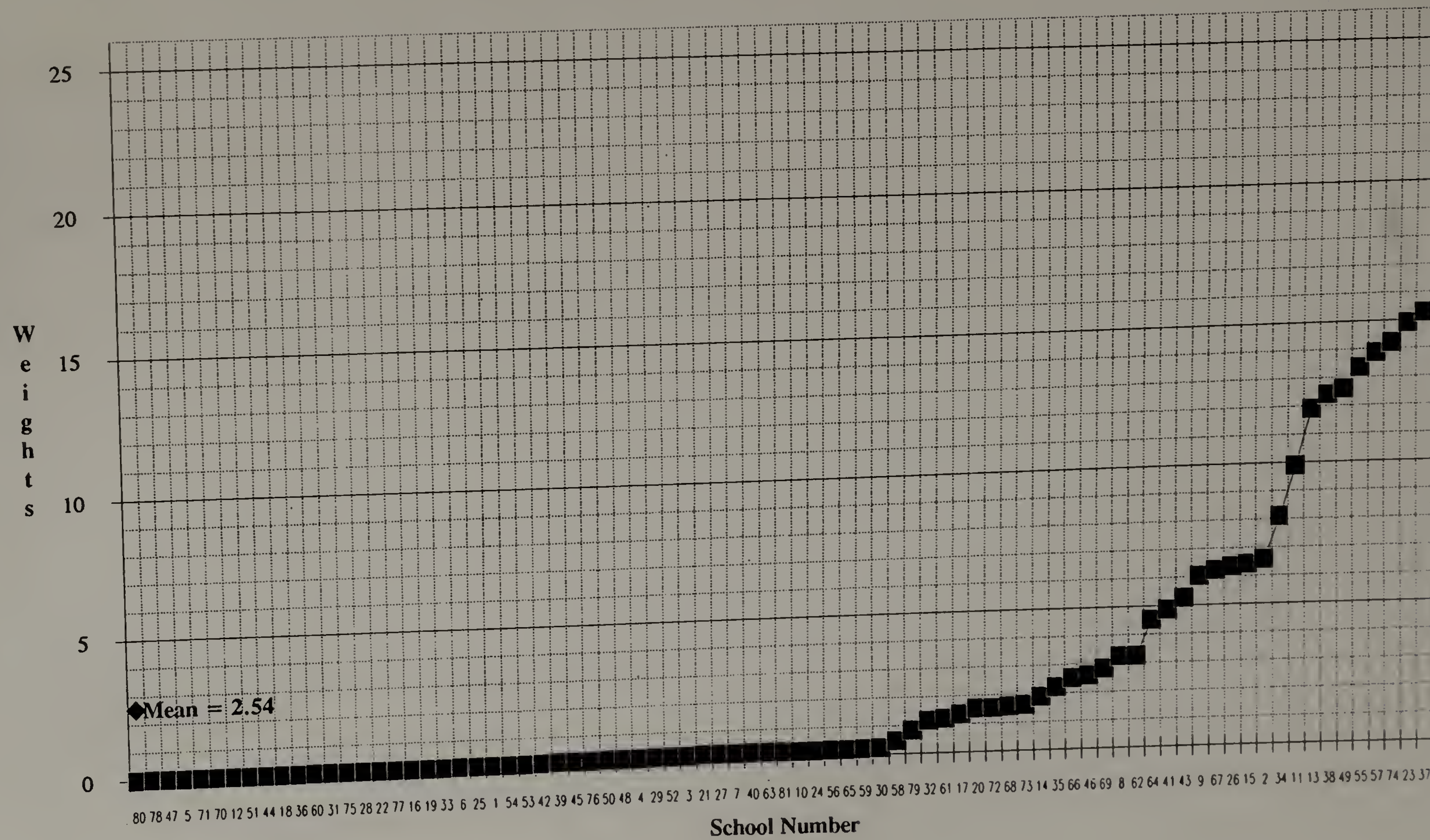


Figure 4.3
Assigned Weights: Mathematics Assessment

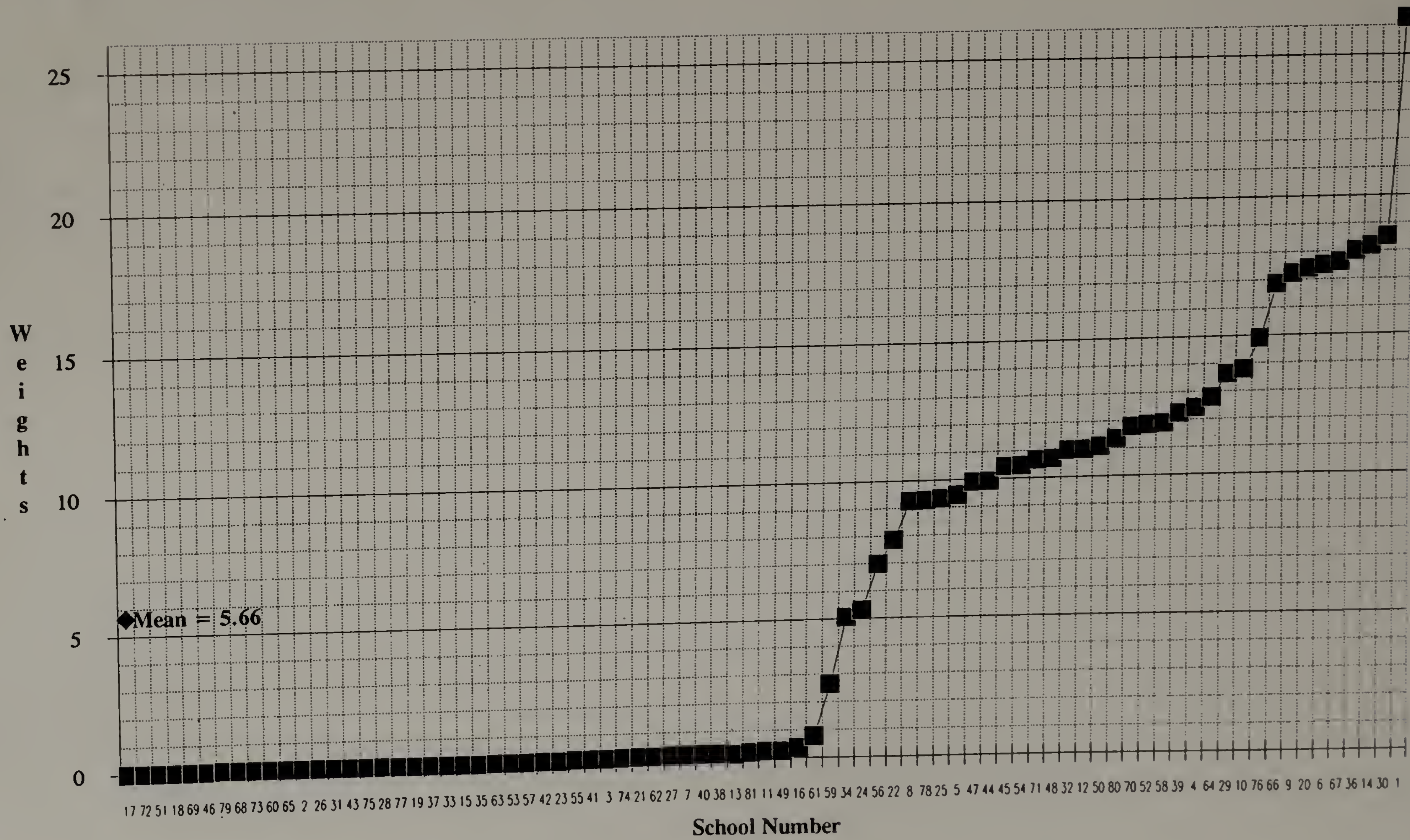


Figure 4.4
Assigned Weights: Science Assessment

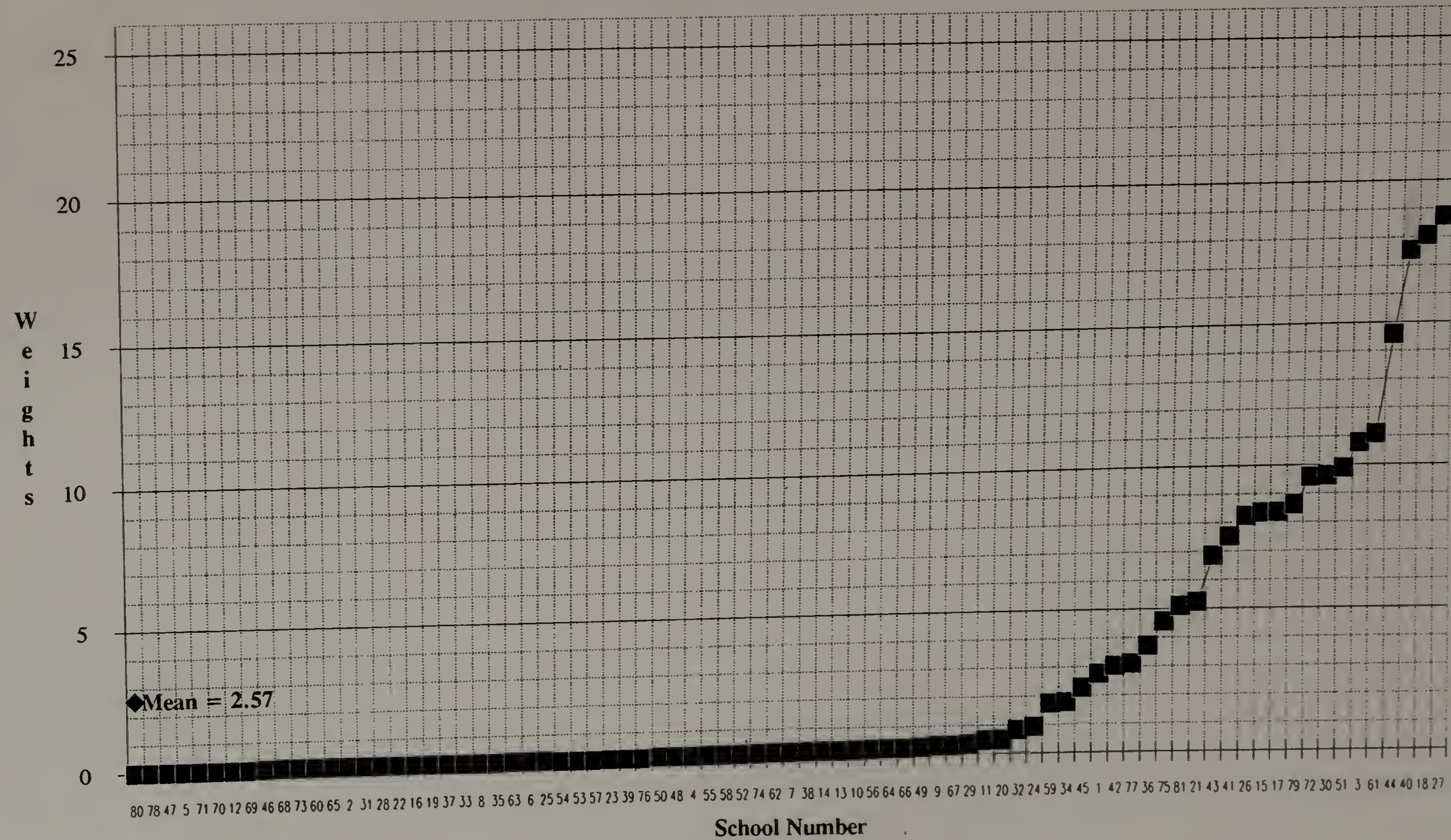


Figure 4.5
Assigned Weights: Social Studies Assessment

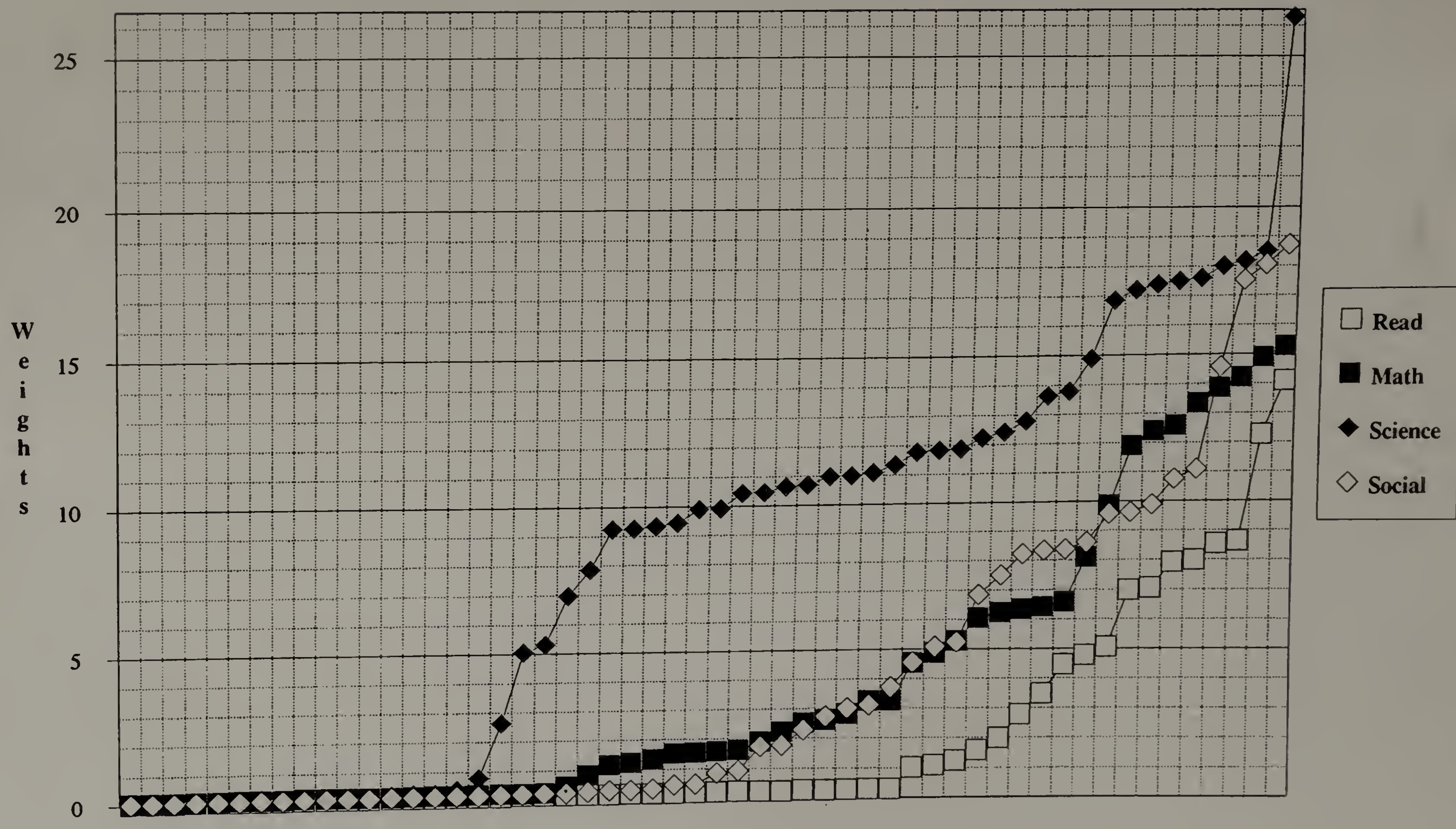


Figure 4.6
Distribution of Output Weights

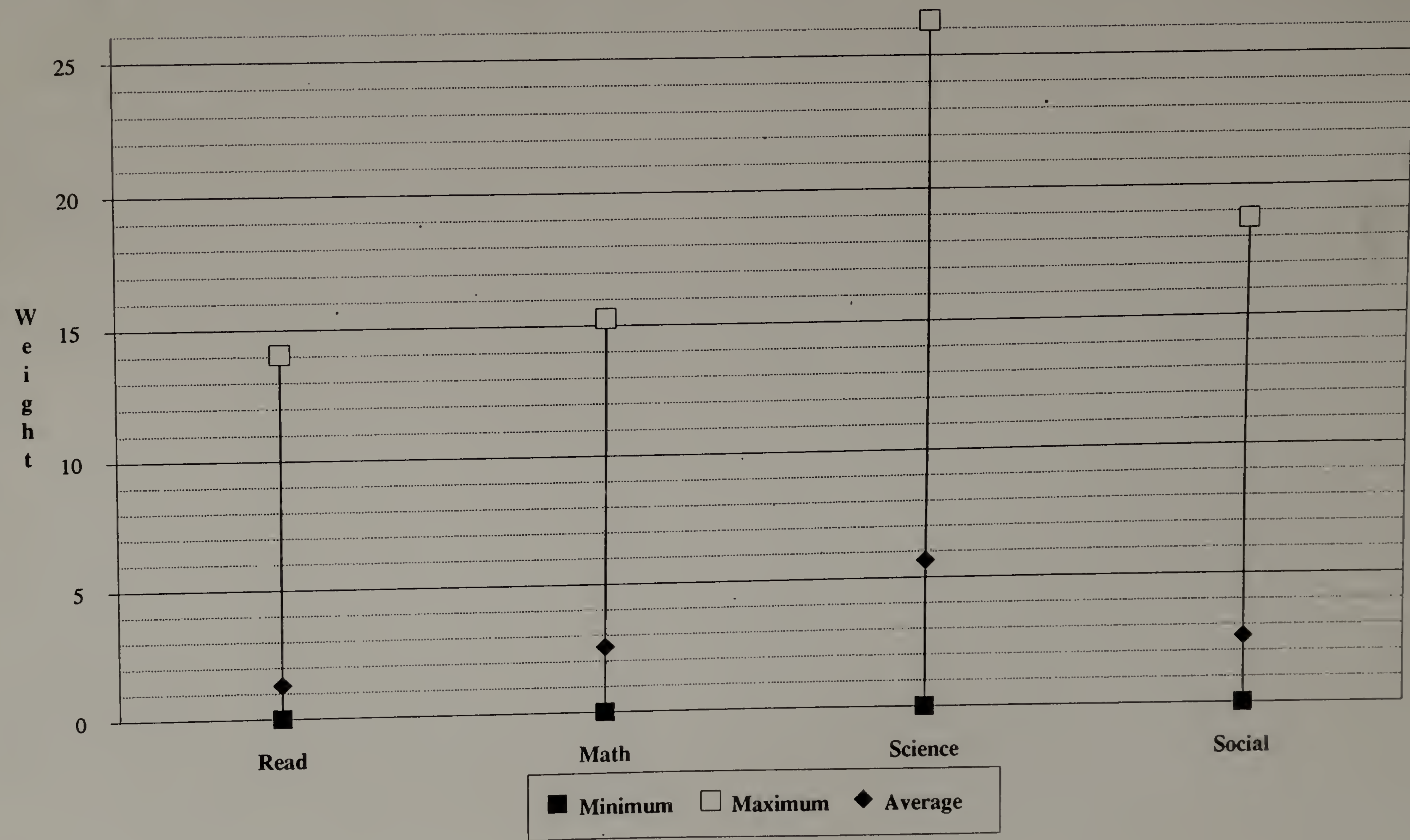


Figure 4.7
Weight Comparison among Output Variables

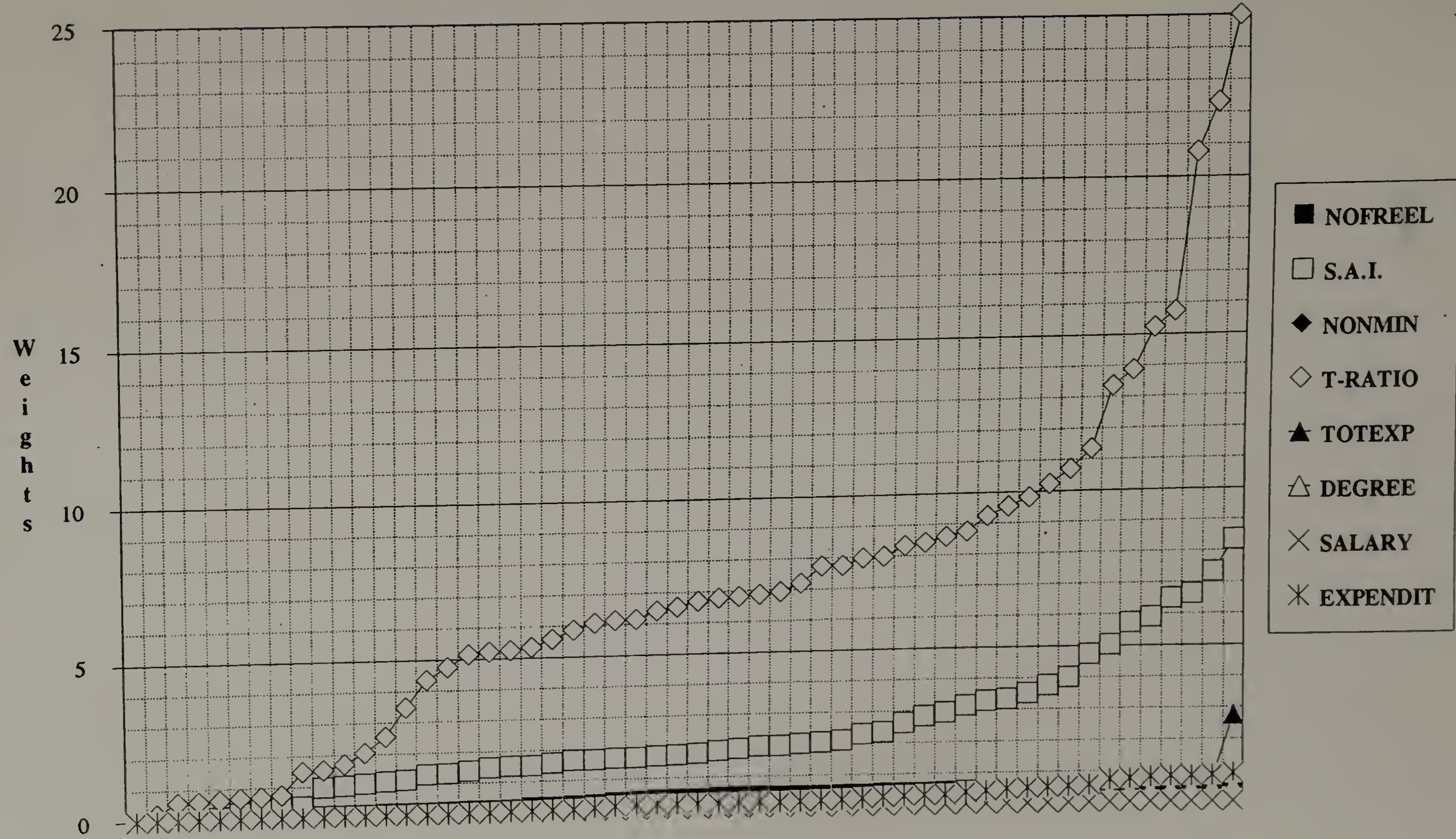


Figure 4.8
Distribution for Input Weights (I)

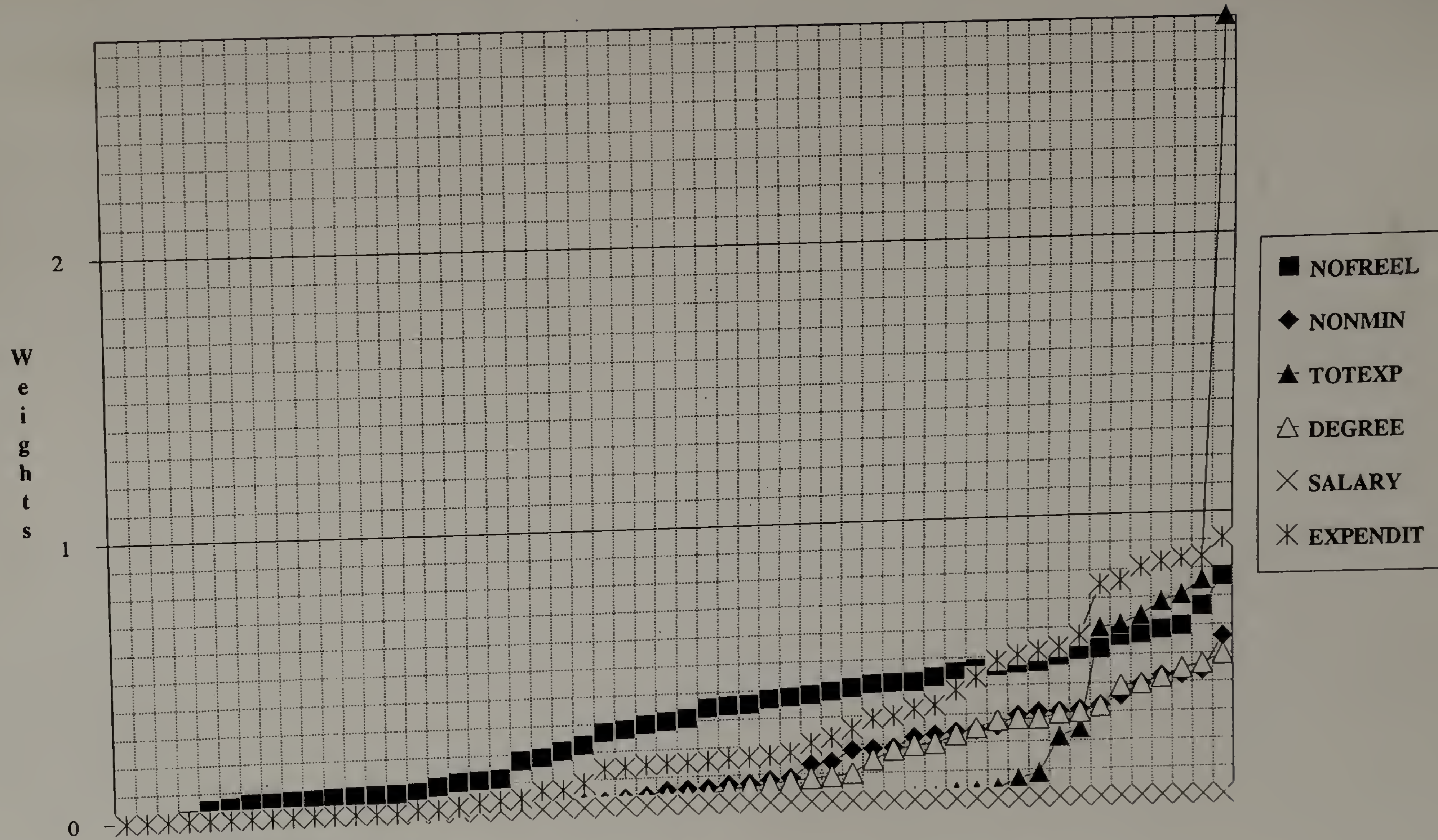


Figure 4.9
Distribution for Input Weights (II)

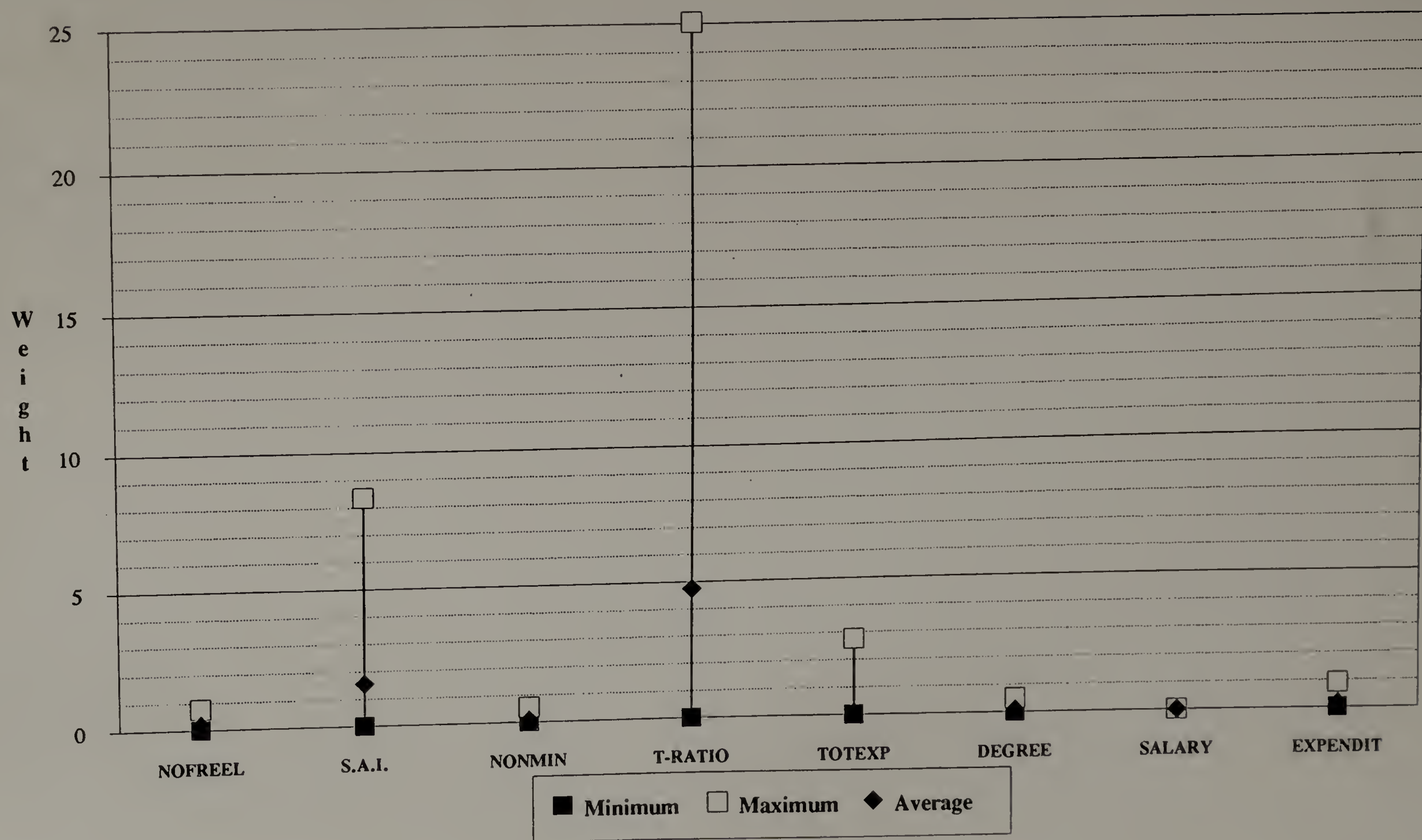


Figure 4.10
Weight Comparison among Input Variables

Efficient Reference Set

Among the results produced by DEA is an efficient reference set (also called a facet) for each school. The facet is a comparison group of efficient schools against which the inefficient school is directly compared and found to be inefficient. Of the 37 schools in our sample that are identified as being efficient, all appear in at least one facet; however, some dominate more often than others. Table 4.7 displays the ten schools which occur most frequently in facets. These schools would be categorized as relatively well-rounded schools with characteristics that less efficient schools might wish to emulate. School #47, for example, tops the list by having been chosen sixty times by DEA to serve as a standard of measurement to determine relative efficiency for other schools.

Table 4.7

Schools Occurring in Facets

DMU Name	Number of Facets
School #47	60
26	45
14	44
71	42
64	35
70	33
5	25
58	21
12	21
29	15

Sensitivity Analysis for Non-School Inputs

Sensitivity analysis tests the sensitivity of the results of DEA to a change in any one of the variables. Thus, the analysis provides an alternate indicator of the strength of a school's apparent efficiency by measuring the extent to which the omission of an input or output would render the school inefficient.

In this case, we are interested in testing the sensitivity of our DEA results to the omission of each of three non-school inputs. Among the eight input measures used in this study, three inputs represent socioeconomic factors (students' home environments and family backgrounds). These inputs are: percentage of non-minority students, percentage of students not eligible for free or reduced price lunch, and the student activity index. Schools do not have control over the first two of these inputs, although schools may alter some of the factors used in the calculation of the student activity index. The graphical representation of the data collected for our 81 schools on each of the three non-school inputs appears in Figures 4.11 through 4.13. In the following sections we discuss the effect of each of these inputs on measures of efficiency.

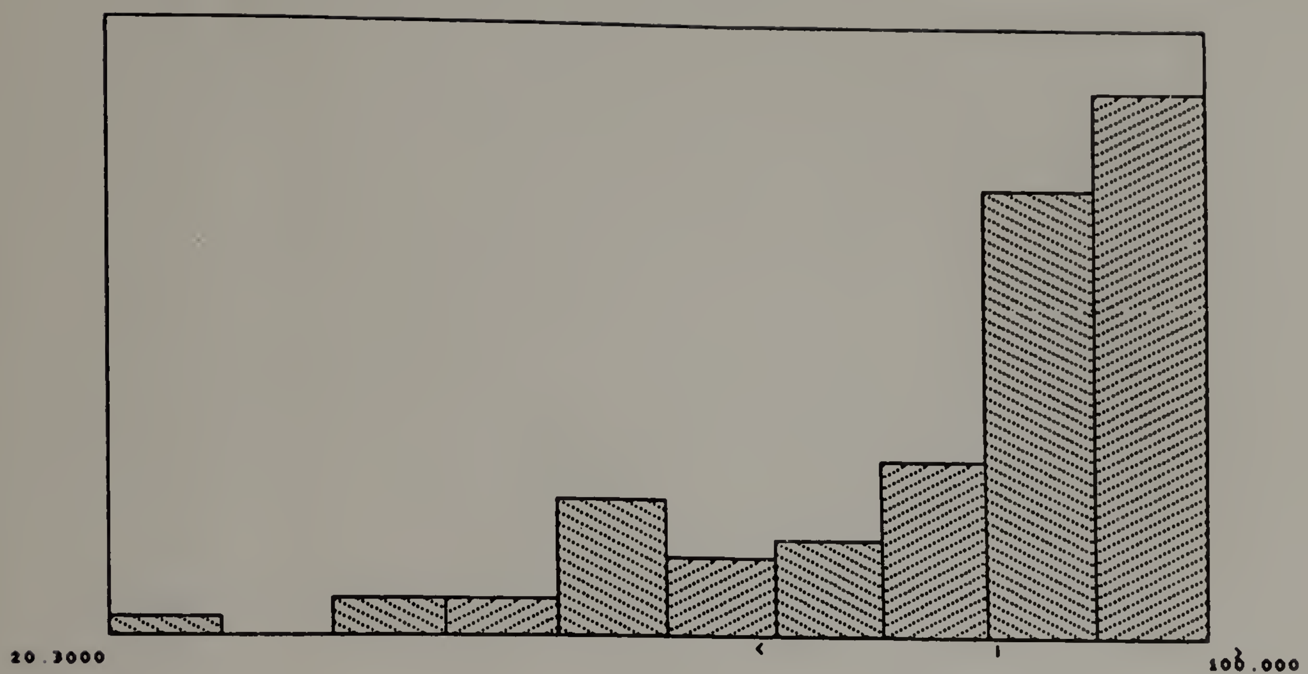


Figure 4.11
Frequency Histogram of Nonminority Input

Mean = 84.3173
Standard deviation = 17.7899
Maximum frequency of 28

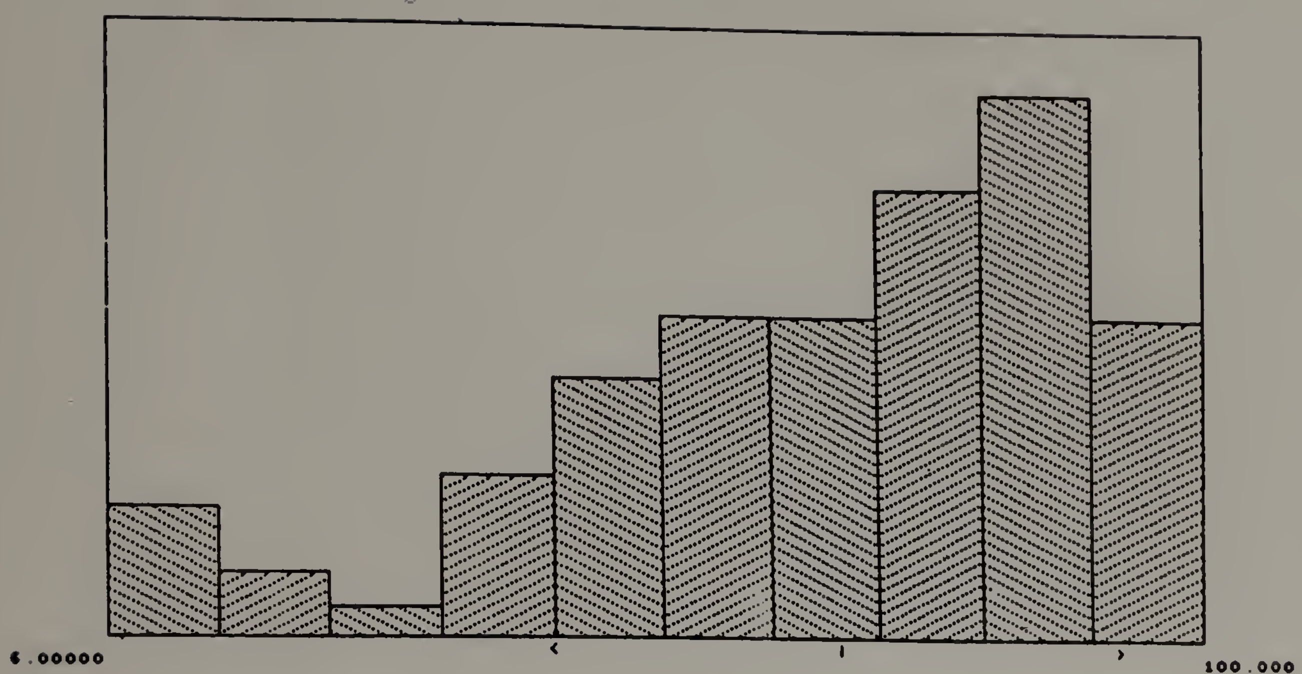


Figure 4.12
Frequency Histogram of Not Eligible for Free or Reduced Price Lunch Input

Mean = 67.9877
Standard deviation = 24.7636
Maximum frequency of 17

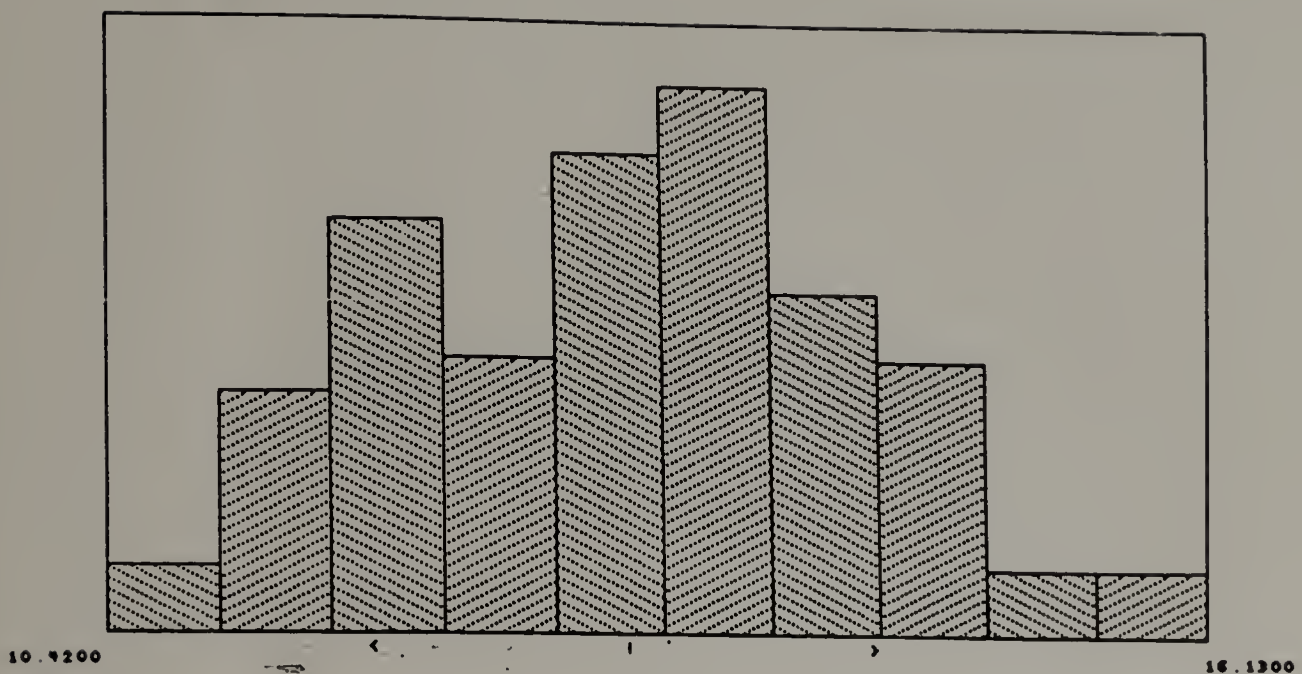


Figure 4.13
Frequency Histogram of Student Activity Index Input

Mean = 13.0648
Standard deviation = 1.31698
Maximum frequency of 16

Exclusion of the Non-Minority Factor. Figure 4.11 clearly illustrates that the distribution of data for the non-minority factor is skewed. To achieve relatively equally sized subgroups we selected a threshold level of 90% thus creating two subgroups: one group of 48 schools having 90% or more non-minority students in fourth grade and the other group of 33 schools having less than 90% non-minority students in fourth grade.

DEA was applied separately to each group, using (in each case) the same four outputs and seven inputs (excluding the percentage of non-minority students input). No differences in efficiency distributuion between subgroups were found.

In the next step of analysis, DEA was applied to all of the 81 schools using four outputs and seven inputs, again excluding the non-minority input. The results indicate that 35 schools are efficient and 46 schools are inefficient. The 35 schools identified as being efficient in this case are among the 37 schools identified as being efficient when the non-minority input is included in the model. The two schools that were efficient in the original model (when the non-minority input is included) and have become relatively inefficient (when the non-minority input is excluded) nevertheless have an efficiency index of .97523 and .98741, respectively. Additionally, when the non-minority input is included in the model, the average of the relative efficiency indices among the inefficient schools is .928;

when the non-minority input is excluded from the model, the average is .926.

From the above evidence -- i.e., when the non-minority input was excluded, only two schools are removed from the efficient frontier and the average efficiency index among inefficient schools remains nearly the same -- we may conclude that the non-minority factor does not determine the frontier membership of schools.

Exclusion of the Free/Reduced Price Lunch Factor. DEA was again applied to our 81 schools using four outputs and seven inputs, this time excluding the percentage of students not eligible for free or reduced price lunch input. The results indicate that 32 schools are efficient and 49 schools are inefficient. The 32 schools now identified as being efficient are among our 37 schools identified as efficient in our original model. Thus, five schools become inefficient when the free/reduced price lunch input is excluded. The average efficiency index for those five schools is .941. The average of the relative efficiency indices among the inefficient schools has again (as in the exclusion of the non-minority input) decreased, but not significantly; originally at .928 when all eight inputs are included, this average decreases to .921 when the free/reduced price lunch input is excluded. We may again conclude, then, that our excluded input does not determine the frontier membership of schools.

Exclusion of the student activity index factor. In this final application of DEA to the 81 schools, the student activity index input was excluded. The results identified 34 schools as efficient and 47 schools as inefficient. Again, the 34 efficient schools in this case appear among the 37 efficient schools in our original model. The average efficiency index of the three schools which have become inefficient remains near efficiency (at .965). The average efficiency index for the 47 inefficient schools is .911, a reduction of less than 2%. The student activity index input, then, also appears not to determine the frontier membership of schools.

The sensitivity analysis of each of the three inputs which represent non-school factors indicates that these factors do not significantly change the efficient frontier. Caution is warranted, however, in regard to two points: 1) We are here evaluating changes within the sample as a whole. When the goal is to evaluate an individual school unit, any and all changes should be carefully analyzed; 2) We are evaluating changes in efficiency in relation to certain inputs. While individually these inputs may not significantly alter efficiency, taken together these inputs may in some cases influence efficiency to a significant degree.

Analysis of Individual Efficient and Inefficient Schools

To this point in our analysis, we have examined efficient and inefficient schools in a broad sense. Such an examination does not reveal specific details about the characteristics of individual efficient or inefficient schools, since each school has its own unique characteristics. To provide better insight, therefore, into the workings of individual schools, we select four schools as a sample for an in-depth analysis.

To form a visual representation of the relationship between efficiency and output for each school, the 81 relative efficiency indices are plotted against each of the four output measures. The results appear in Figures 4.14 through 4.17. This action lays the ground work for a system of quadrant analysis first suggested by E. W. Bessent[2]. When we imagine a set of two axes -- one drawn vertically at the efficiency index of .9 and one drawn horizontally at the average assessment test score of 1300 -- we have a visual plane on which each school appears in one of four quadrants which can be used to describe the relationship between efficiency and output. Thus, we have one group of schools with efficiency indices above .9 and test scores above average, a second group of schools with efficiency indices above .9 and test scores below average, a third group of

[2]This system of quadrant analysis, originated by E. W. Bessent, was used by Bessent, Bessent, Kennington and Reagan (1982) and by Splitek (1981) at E. W. Bessent's suggestion.

schools with efficiency indices below .9 and test scores above average, and a fourth group of schools with efficiency indices below .9 and test scores below average.

For analysis, we have chosen four schools (which individually fall consistently into one quadrant for each of the four output measures) -- one school to represent each of the quadrants. School #63 has an efficiency index of one and has consistently high scores on the reading, mathematics, science and social studies assessment tests. School #16 is also efficient, with an index of one, but its scores on the assessment tests are consistently low. (And, in fact, on the reading and science tests, school #16 falls at the bottom of our sample of 81 schools). School #45 is relatively inefficient but, nevertheless, has assessment test scores consistently slightly above average. School #7 is also relatively inefficient and produces consistently low assessment test scores.

In analyzing the results produced by DEA for each school, two conditions must be met for efficiency to exist: 1) the values of Theta must equal one; and 2) the sum of the slack values must equal zero. Iota, the measure of efficiency which satisfies the two conditions, will then equal one. The values of Theta, Iota and the sum of the slack values for all 81 schools appear in Appendix G.

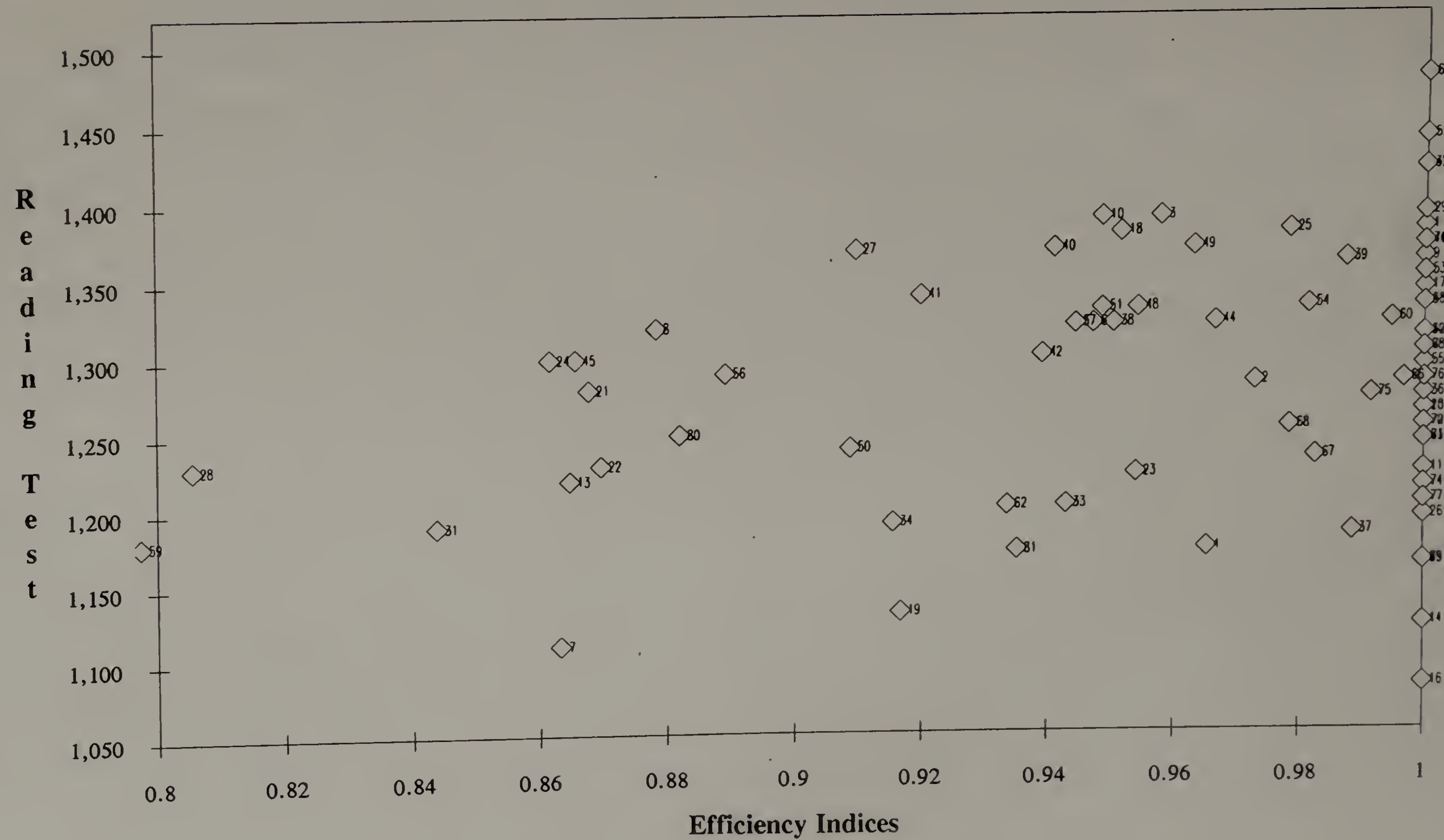


Figure 4.14
Average Reading Test Score vs. Efficiency Indices

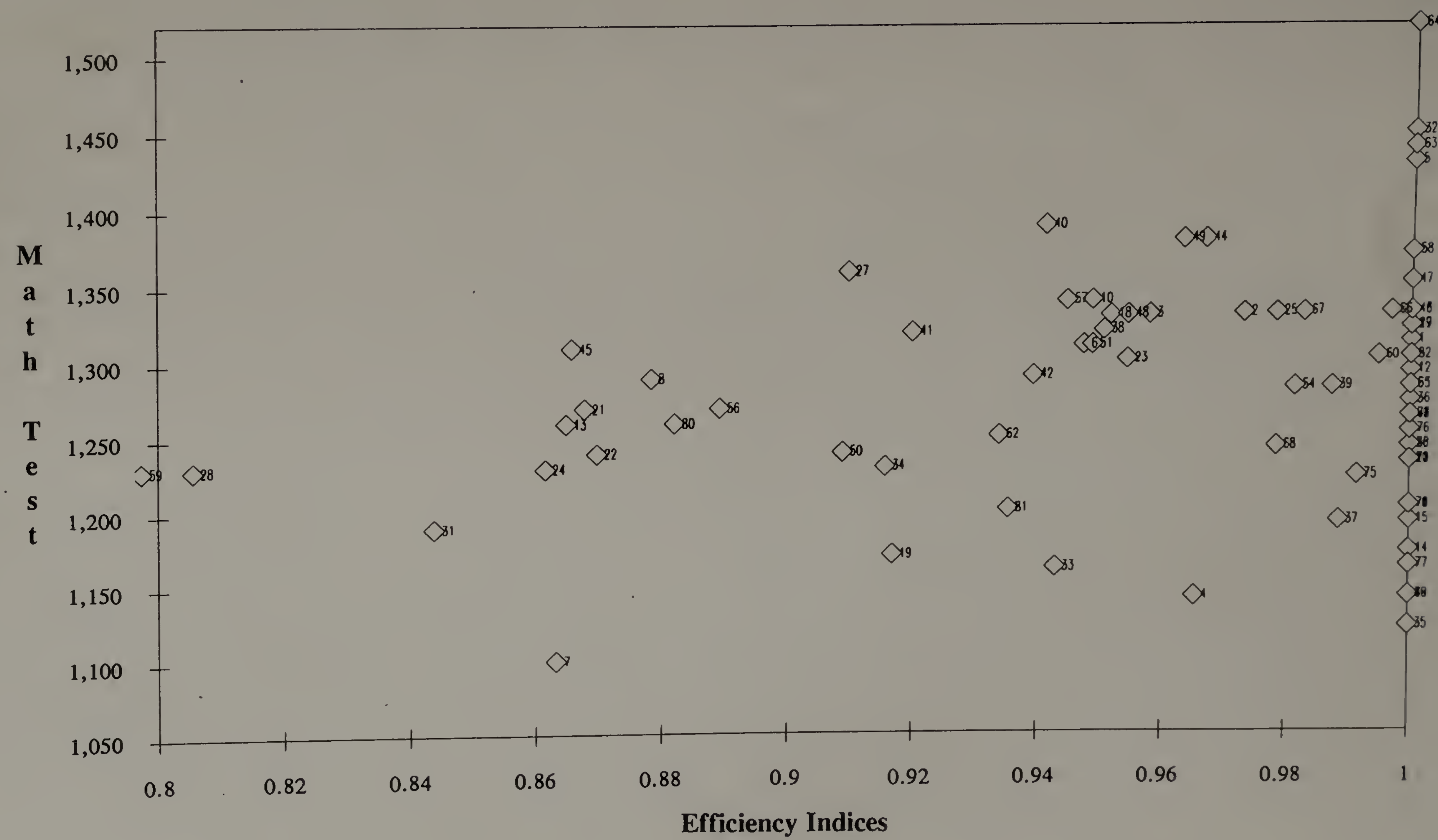


Figure 4.15
Average Math Test Score vs. Efficiency Indices

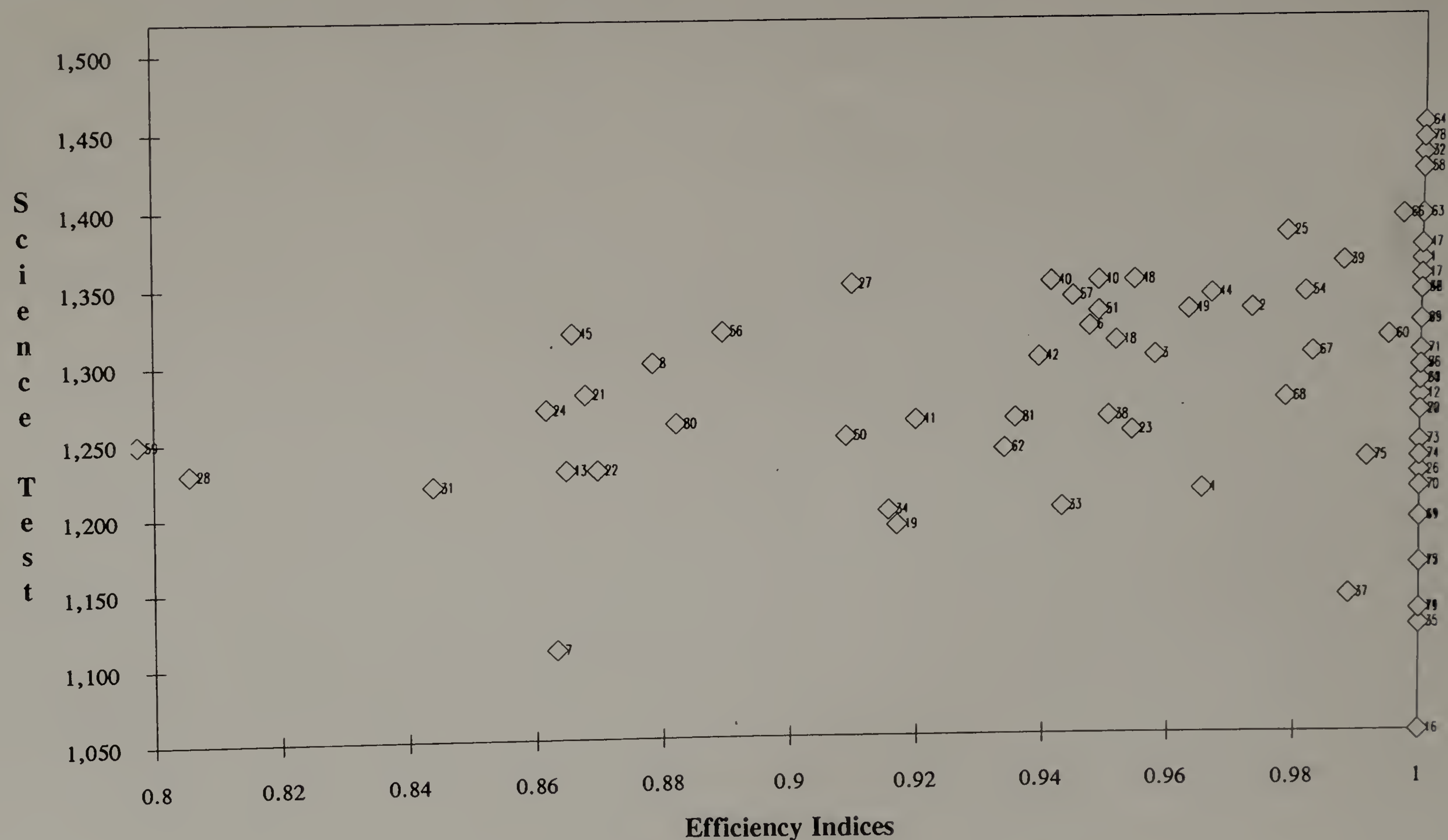


Figure 4.16
Average Science Test Score vs. Efficiency Indices

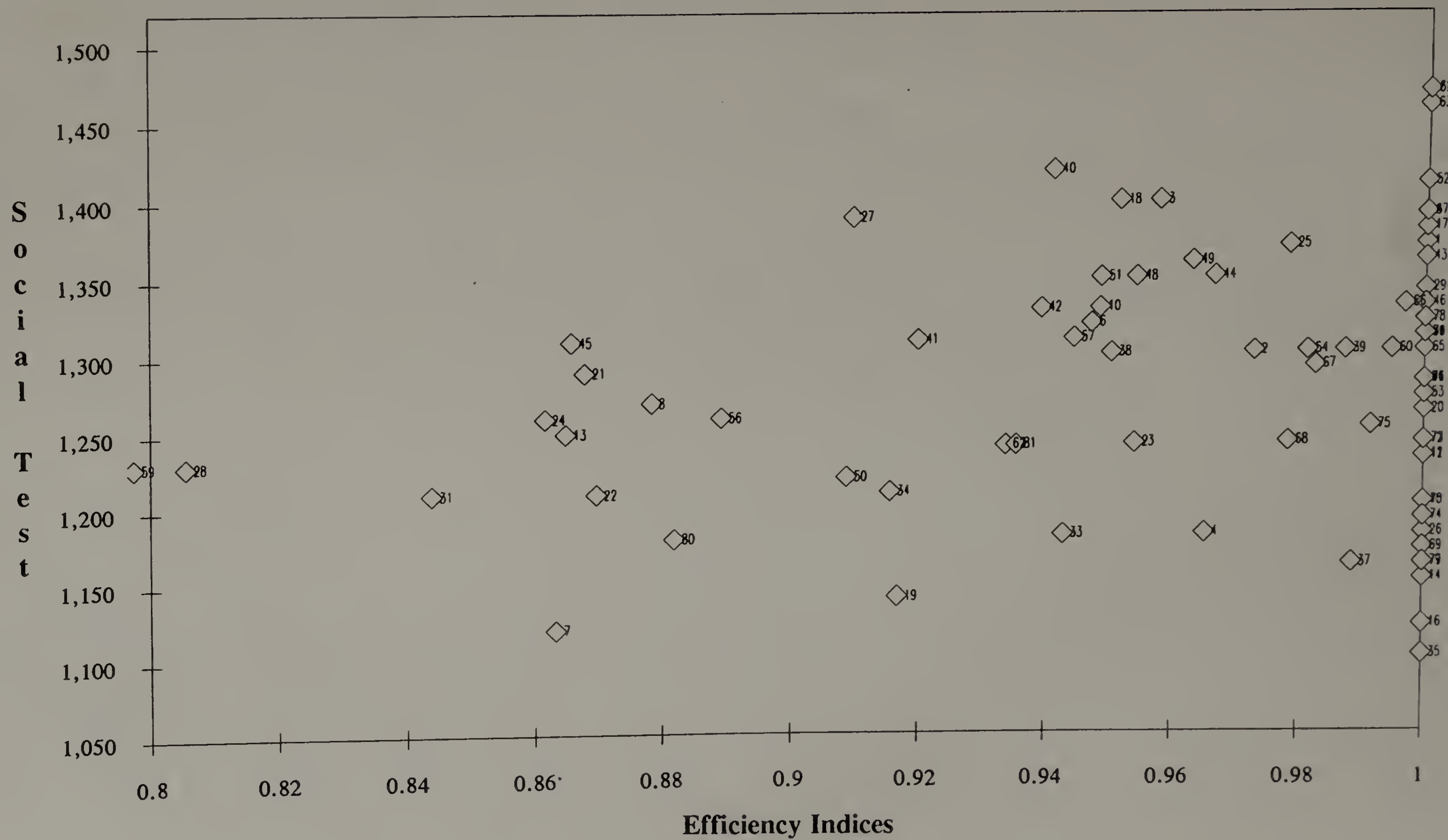


Figure 4.17
Average Social Studies Test Score vs. Efficiency Indices

Tables 4.8 through 4.11 summarize the results of DEA for the four schools we have chosen to examine. The results for school #63, which occupies the quadrant representing high efficiency and high achievement, appear in Table 4.8.

The efficiency index for school #63 is one (Iota = 1). Thus, Theta equals one, and the sum of the slack values equals zero. The efficient reference set (facet) includes the group of schools against which school #63 was compared. Lambda represents the relative weight assigned to each member of the facet to indicate the relative importance of each comparison in calculating the efficiency rating. Since school #63 is efficient, the only weight is assigned to itself.

Mu and Nu represent the relative weights assigned to the output and input measures, respectively. School #63 produces highest output on the reading assessment, and this dominance is reflected in the assigned weights. The column labeled "measured" records the actual values for each output and input measure used for this analysis. The column labeled "projection" lists the values for each output and input that would make the school efficient. In the case of school #63, the values in the "measured" and "projection" columns are equivalent, indicating that school #63 is efficient. The column labeled "slack" indicates slack values, i.e., the increase in output or the additional decrease in input that would cause the school to become efficient. For school #63 the summation of the slacks is zero, which again indicates that this school is efficient.

Table 4.8

DEA Results for School #63

Model Solved: P-BCC

Unit: 63 Name: School 63
Theta: 1.0000
Sum of Slacks = .00

Facet:	71	52	64	70	72	63
Lambda:	.00	.00	.00	.00	.00	.00
Mu:	14.074	.150	.037	.037		
Nu:	.00037	.00037	.55799	6.4213		
	.00037	.00037	.00037	.06853		

Iota: 1.000

	Measured	Projection	Slack
OUTPUTS			
Read	1480.00	1480.00	.00
Math	1440.00	1440.00	.00
Science	1390.00	1390.00	.00
Social	1460.00	1460.00	.00
INPUTS			
NOFREEL	99.00	99.00	.00
S.A.I.	13.07	13.07	.00
NONMIN	92.00	92.00	.00
T-RATIO	4.62	4.62	.00
TOTEXP	24.34	24.34	.00
DEGREE	200	200	.00
SALARY	34567.00	34567.00	.00
EXPENDIT	87.50	87.50	.00

DEA results for school #16, which occupies the quadrant representing high efficiency but low achievement, appear in Table 4.9 As we would expect, there are no slack values for school #16 since it is an efficient school. Nevertheless, assessment test scores are below average, indicating a need to improve student learning. Thus, the DEA results are somewhat problematic; they tell us that, of the specific inputs tested, school resources are being used efficiently to product output -- but the expected output is not being achieved.

In such a case, the input measures themselves may provide clues as to what action may be taken to improve output. Since school resources are being used well, it becomes necessary to examine non-school factors. The inputs representing those factors tell us that school #16 has a high percentage of students who are eligible for free or reduced price lunch (94% of fourth grade students), thus suggesting that many students may come from economically disadvantaged families. The data also suggest that a relatively high percentage (59%) of fourth grade students come from minority family backgrounds.

Two possibilities immediately arise; students may have multiple socioeconomic hurdles to overcome in their daily lives in addition to the task of learning in school, and cultural bias may exist in curricular objectives and content, instructional materials, assessment tests, or teachers' attitudes. In either case, more study may be necessary to know what problems individual students are facing in their home and school environments and how teachers might help to overcome those problems. The inputs that were aggregated in this study to form the student activity index may be useful in further study directed toward these problems. These inputs, and others like them, seek to measure students' and parents' attitudes toward learning, to determine whether the home environment supports and enriches student learning.

Table 4.9

DEA Results for School #16

Model Solved: P-BCC

Unit: 16 Name: School 16
Theta: 1.0000
Sum of Slacks = .00

Facet:	70	14	16	26	79	15	17
Lambda:	.00	.00	1.00	.00	.00	.00	.00
Mu:	4.777	.024	.375	.024			
Nu:	.4580	2.628	.0002	5.582			
	.0002	.2792	.0002	.0002			

Iota: 1.000

	Measured	Projection	Slack
OUTPUTS			
Read	1080.00	1080.00	.00
Math	1140.00	1140.00	.00
Science	1050.00	1050.00	.00
Social	1120.00	1120.00	.00
INPUTS			
NOFREEL	6.00	6.00	.00
S.A.I.	13.55	13.55	.00
NONMIN	40.70	40.70	.00
T-RATIO	3.41	3.41	.00
TOTEXP	7.00	7.00	.00
DEGREE	134.00	134.00	.00
SALARY	21667.00	21667.00	.00
EXPENDIT	87.50	87.50	.00

The DEA results for school #45, which occupies the quadrant representing low efficiency with relatively high achievement, appear in Table 4.10. The efficiency index

(Iota) for this school is .86513. The efficient reference set (facet) identifies eight schools which exist on the efficient frontier to which school #45 is most directly related. The weights assigned to each of those eight schools become the coefficients (Lambda) that are used to generate a hypothetical efficient school most similar to school #45. Thus, Lambda is multiplied by each output and input of each facet school to generate the projected hypothetical school (whose outputs and inputs appear in the column labeled "projection").

The slack values for output measures are calculated as the difference between the projected value for outputs ("projection") and the actual values for outputs ("measured"). For school #45, slack values for outputs appear only for the reading and mathematics tests.

The slack values for input measures represent the remaining additional decrease in an input necessary to achieve efficiency after the overall proportional reduction by Theta. They are calculated as follows for inefficient schools: Theta (a necessary condition for efficiency) is multiplied by the input's actual value, and then the projected value of the input is subtracted.

✓ Slack = (Theta) * ("measured") - ("projection")

For example, the first input for school #45, the percentage of students not eligible for free or reduced price lunch, is calculated as follows:

Slack = (.8732725) (86) - (75.10) = 0

The last input for school #45, per student expenditure on instructional materials, is calculated as:

Slack = (.8732725) (115) - (84.57) = 15.86

Table 4.10

DEA Results for School #45

Model Solved: P-BCC

Unit: 45	Name: School 45							
Theta: .8732725								
Sum of Slacks = 1230.11								
Facet:	5	14	64	26	47	70	71	58
Lambda:	.003	.016	.270	.413	.161	.00	.108	.031
Mu:	.066	.066	10.438	2.278				
Nu:	.1869	.9689	.22245	5.859				
	.0006	.0241	.0006	.0006				
Iota:	.86513							

	Measured	Projection	Slack
<u>OUTPUTS</u>			
Read	1300.00	1328.00	28.39
Math	1310.00	1335.52	25.52
Science	1320.00	1320.00	.00
Social	1310.00	1310.00	.00
<u>INPUTS</u>			
NOFREEL	86.00	75.10	.00
S.A.I.	13.27	11.59	.00
NONMIN	92.50	80.78	.00
T-RATIO	4.17	3.64	.00
TOTEXP	18.67	11.84	4.46
DEGREE	134.00	117.02	.00
SALARY	34334.00	28827.06	1155.88
EXPENDIT	115.00	84.57	15.86

Table 4.11

DEA Results for School #7

Model Solved: P-BCC

Unit: 7 Name: School 07
Theta: .8686733
Sum of Slacks = 381.89

Facet:	16	70	14	26
Lambda:	.053	.657	.215	.076
Mu:	.144	.144	.144	.144
Nu:	.00144	1.0026	.00144	6.7009
	.00144	.00144	.00144	.20851

Iota: .86316

	Measured	Projection	Slack
OUTPUTS			
Read	1110.00	1208.00	98.54
Math	1100.00	1193.40	93.40
Science	1110.00	1185.10	75.10
Social	1120.00	1183.51	63.51
INPUTS			
NOFREEL	41.00	34.37	.00
S.A.I.	14.21	12.34	.00
NONMIN	76.40	49.77	16.60
T-RATIO	4.48	3.89	.00
TOTEXP	5.67	3.95	.97
DEGREE	167.00	112.55	32.52
SALARY	25667.00	22296.24	.00
EXPENDIT	87.50	76.01	.00

Further analysis of school #45 will include suggestions, in the next section of this chapter, to improve its efficiency rating. School #7, which occupies the low efficiency-low achievement quadrant, follows the same line of analysis, although its slack values for outputs and inputs are, of course, different; therefore, an analysis of school #45 will serve to guide improvement of inefficient schools attaining all levels of output, and the results of DEA for school #7 will appear only in Table 4.11.

<u>Improving the Efficiency Rating of an Inefficient School</u>

Our goal, as educators, is to help schools use their resources efficiently to create quality learning for all students. With inefficient schools, our first task is to help these schools use their current resources efficiently. From that point, we are then better prepared to take the next step of helping schools to identify how they can further improve student learning, including the possibility that schools may need to apply more resources to their efforts.

Thus, the first task is to help the inefficient school become efficient. School #45 has again been chosen to illustrate the process. (It will be remembered that the DEA results for school #45 appear in Table 4.10).

There is a two-step process for using DEA results to make an inefficient school's input levels efficient. Step one involves the proportional reduction of inputs, by multiplying each input value by Theta. This act will make Theta equal to one, which is a necessary condition for efficiency. Step two is to additionally reduce each input by the amount of the slack value for that input. Taken together, these two steps will determine the amount of excess for each input which is being overconsumed. Table 4.12 shows the excess inputs for school #45, which is the difference between "measured" and "projection." The last column of Table 4.12 shows the percentage of excess inputs. The overall reduction of inputs by these amounts will increase the efficiency of school #45.

Table 4.12

Excess Input for School #45

Input	Measured	Projection	Excess Input	Percentage of Excess Input
NOFREEL	86.00	75.10	10.9	12.67
S.A.I.	13.27	11.59	1.68	12.66
NONMIN	92.50	80.78	11.72	12.67
T-RATIO	4.17	3.64	.53	12.71
TOTEXP	18.67	11.84	6.83	36.58
DEGREE	134	117.02	16.98	12.67
SALARY	34334	28827.06	5506.94	16.04
EXPENDIT	115.00	84.57	30.43	26.46

Of the eight inputs, some -- particularly the non-school factors (the percentage of students not eligible for free or reduced price lunch, the percentage of non-minority students, and the student activity index) -- will not be alterable, or can only be influenced over long periods of time. For example, the inputs measured by the student activity index (i.e., parents' and students' attitudes toward learning) may be influenced by the school in time.

As shown in Table 4.12, school #45's greatest levels of overconsumption of resources occur for three inputs: teachers' total years of experience (36%), per student expenditure on instructional materials (26%), and teachers' salary (16%). School administrators may be able to control expenditures on instructional materials, but teachers' experience and teachers' salaries are not easily controlled at the school level. Nevertheless, the knowledge that overconsumption is occurring in the use of these resources gives direction to efforts toward improvement. Further study done within the individual school may uncover the ways in which overconsumption is occurring. For example, teachers may be misassigned to areas of expertise and personal interest, or instructional methods may not tap the full range of teachers' know-how and experience. Recommendations to correct the overconsumption of these inputs can be made only after knowledge of the circumstances unique to that school is gained.

The final step toward efficiency for school #45 involves the school's output measures. If output slacks had been zero, then the school would now be efficient. Since, however, there are slack values for outputs, the output measures need to be increased by the amount of the slacks to make the school efficient. For school #45, that means that once overconsumed resources have been reduced, the average reading and mathematics test scores should also be improved by 28.39 and 25.52 points, respectively.

Chapter Summary

Chapter IV, Analysis of the Data, discussed the results of Data Envelopment Analysis as applied to our 81 elementary schools in Western Massachusetts. Analysis of the results of the DEA model proceeded in three phases, each phase corresponding to a major research question guiding the study.

<u>Research Question #1</u>: How do the selected elementary schools differ as to the degree of inefficiency when compared with each other?

The results of DEA produced an efficiency index (Iota) for each school. Of 81 schools, 37 (or 46%) were determined to be efficient and 44 (or 54%) were found to be inefficient to varying degrees.

To determine what accounts for differences in degrees of efficiency, schools were separated into two groups (efficient versus inefficient) to which descriptive statistical tests (F-tests and t-tests) were applied. Results indicated no significant differences between output measures of the two groups. Five of the eight inputs were found to be significantly different between efficient and inefficient schools; they include: percentage of non-minority students, average total years of teachers' experience, teachers' level of education, teachers' average salary, and per student expenditure on instructional materials.

<u>Research Question #2</u>: What factors may account for differences in expected achievement (output) among relatively efficient schools?

The data generated by DEA was applied to move the 44 inefficient schools to the efficient frontier. Multiple regression analysis of the 81 now efficient schools was then used to determine what factors may account for differences in expected achievement. The regression results indicated that four factors -- the percentage of students not eligible for free or reduced price lunch, the percentage of non-minority students, teacher-student ratio, and teachers' average salary -- may contribute to differences in expected student achievement among relatively efficient schools.

Research Questions #3: What factors may account for differences in relative efficiency scores?

In answering this question, a broader picture of efficient and inefficient schools was first presented. Next, an analysis of some individual efficient and inefficient schools was discussed. Finally, suggestions were provided to improve the efficiency rating of a selected inefficient school.

DEA provided information on slack values and relative weights for each input and output. Slack values represent the degree of overconsumption of resources in inefficient schools; that is, they indicate the reduction in inputs and increase in outputs that are necessary for efficiency. Slack was found to exist for five of our eight inputs in more than half of our 44 inefficient schools. These inputs are the same five that were identified for research question #1 as accounting for significant differences between efficient and inefficient schools. The figures for slack values imply that overconsumption of resources occurs most frequently in the use of these inputs.

Relative weights were assigned by DEA to each school's outputs and inputs to maximize its efficiency rating. The highest weights were, therefore, assigned both to the highest levels of outputs and the lowest levels of inputs.

For each inefficient school, DEA identified a set of efficient schools (called the efficient reference set, or facet) against which the inefficient school was found to be most directly inefficient. Relative weights were assigned to each member of the facet to indicate the relative importance of each comparison in calculating the efficiency rating of the inefficient school.

Sensitivity analysis was applied to test the sensitivity of the DEA results to a change in any one of three non-school factors: the percentage of non-minority students, the percentage of students not eligible for free or reduced price lunch, and the student activity index. DEA was applied, excluding one non-school input in each application, to the resulting set of four outputs and seven inputs. Although a few individual schools became less efficient when DEA was applied in this manner, the efficiency frontier was not significantly altered. It was, therefore, concluded that the DEA efficiency results are relatively robust in regard to these inputs.

In the analysis of individual efficient and inefficient schools, quadrant analysis was introduced. Quadrant analysis allows us to classify schools into one of four groups which describe the relationship between efficiency and output achievement. The DEA results for schools #63, #16, #45, and #7 were individually analyzed. These schools are individually representative of each of the four quadrants.

School #45, which represents relatively low efficiency and high achievement, was chosen for evaluation in making an inefficient school more efficient. DEA results were used to suggest a reduction in the school's inputs in a two-step process and an increase in some levels of output. Where inputs are nonmanipulable, they may nevertheless indicate sources of inefficiencies for further investigation.

CHAPTER V

SUMMARY, CONCLUSIONS, IMPLICATIONS

Summary

Growing concern for accountability in public education in the 1980s has led to the identification of the individual school as the unit of production of student learning on which improvement efforts must focus. A school may be viewed as an enterprise in which the professional staff provide the operating conditions for converting quantifiable resources (or inputs) into student learning (outputs). School administrators can increase the productivity of individual schools through the hiring and assignment of personnel and through the provision of resources and incentives that have the potential for increasing production if they are efficiently employed (Bessent et al. 1982).

The purpose of this study is to examine the issue of efficiency in public elementary schools. The study employs Data Envelopment Analysis (DEA) as a method of efficiency measurement to determine the extent of inefficiency for 81 non-rural public elementary schools in Western Massachusetts.

DEA was developed in response to a need for management information, which was largely missing, about the relative productivity of schools. DEA is a comprehensive, computer assisted mathematical model for making comparisons across wide ranges of input levels and mixes and schools' outputs. No other method provides an overall operational definition -- either conceptually or implementationally -- of the efficiency of a school (Bessent et al., 1982).

DEA, applied to our sample of 81 schools, produced an empirically-based measure of each school's ability to produce desired outputs from inputs. Outputs were defined as the mean scores on four cognitive sub-tests of the Massachusetts Educational Assessment Program for fourth grade students in 1988 (aggregated at the school level). Sixteen inputs, representing a balance of school resources, student resources and teaching resources, were selected from a review of the educational production function literature. Preliminary analysis reduced the original collection of input measures to eight. DEA results for each school included estimates of the augmentations in outputs and/or the reductions in inputs (i.e., slack values) that should be attained if efficiency were to be achieved.

Conclusions

Analysis of the DEA results proceeded according to three major research questions which guided the study.

Research Question #1

How do the selected elementary schools differ as to the degree of inefficiency when compared with each other?

Of 81 schools, 37 (or 46%) were found to be efficient and 44 (or 54%) were found to be inefficient to varying degrees. Five inputs were found to be significant in determining a school's relative efficiency index: percentage of non-minority students, average total years of teachers' experience, teachers' level of education, teachers' average salary, and per student expenditures on instructional materials.

It should be remembered that we are dealing only with technical efficiency, that is, with the organization of available resources in such a way that maximum feasible output is produced. Our DEA results do not reflect price efficiency.

The results do reflect a high degree of confidence. DEA allows the production function for each school to remain unspecified; thus, the uniqueness of each school is taken into account and all outputs are explicitly identified.

Limitations result primarily from unavailability of data. Data on teacher characteristics, which were obtained through questionnaires, restricted the sample size for this study from a possible 186 schools to 81 due to the response rate. Measures of student learning were restricted to cognitive outputs, although many other school outputs are valued. The Massachusetts Educational Assessment Program provided data that would not have been available before the program's inception, particularly for inputs that were taken from student, teacher and principal questionnaire responses. Output measures for the elementary schools were, nevertheless, restricted to aggregated test scores at the fourth grade level. This level of aggregation was adequate for the purpose of this study. If detailed individual school planning information were required, however, output measures for all grade levels aggregated by classroom would be necessary (Bessent et al. 1982).

<u>Research Question #2</u>

What factors may account for differences in expected achievement (output) among relatively efficient schools?

Four inputs -- the percentage of students not eligible for free or reduced price lunch (proxy for student's family income), the percentage of non-minority students, the teacher-student ratio, and the average salary of teachers -- were found to be most significant in contributing to differences in expected student achievement among relatively efficient schools.

To arrive at valid conclusions to this research question, the factor of inefficiency in schools was eliminated. DEA results allowed us to manipulate the variable so that all schools were moved to the efficient frontier. It could then be assumed that all schools were equally capable of using their resources as efficiently as possible, thus giving us a truer picture of the significant relationships among input and output variables.

Research Question #3

What factors may account for differences in relative efficiency scores?

Five inputs were identified by DEA as contributing most to differences in relative efficiency scores by being overconsumed, or underutilized, in significant numbers of schools. These inputs include: teachers' years of experience, percentage of non-minority students, level of teachers' education, teachers' average salary, and per student expenditures on instructional materials. Thus, three areas of resources in education can be characterized as inefficient: 1) teaching resources, as measured for example by the experience teachers bring to the learning environment; 2) student resources, as measured for example by the percentage of non-minority students; 3) school financial resources, as measured for example by expenditures on instructional materials.

When DEA results are examined to assess the relationship of an individual school's effectiveness for student learning to its efficiency in utilizing its resources, several general recommendations may be made. It should be noted that DEA does not provide absolute measures of efficiency. Rather, schools are compared to an identified peer set of schools that are similar in their levels and mixes of inputs. School administrators must measure how well their schools perform relative to a norm. Thus, if an efficient school succeeds in raising its achievement more than others, then some schools that were formerly efficient may become inefficient and some inefficient schools may be reduced to even greater inefficiency (Bessent et al. 1982).

The strength of DEA lies in its ability to identify both sources and amounts of inefficiencies for specific resources, as well as a peer set of schools for comparison. Schools which are identified as being relatively efficient while having high levels of outputs can, therefore, be studied by less efficient schools to identify what practices the more successful schools are using. Schools which are using their resources inefficiently yet are achieving relatively high levels of outputs can be examined to see whether slack resources could be reallocated to needier schools. Where those resources are given to schools which can produce only low levels of output with efficient use of their existing resources, we can (theoretically) expect greater levels of student learning to be the outcome.

Where schools are both relatively inefficient and achieving low levels of outputs, two approaches exist. School practices can first be adjusted to use existing resources more efficiently, and the school can then be granted additional resources to further improve student learning. Or, these schools can be given additional resources immediately to create better learning conditions and can then be improved to use existing resources more efficiently. The first of these two approaches would seem to appear more logical in most cases, except where there is great disparity in conditions for student learning among schools.

The important point to be made is that DEA results must be carefully examined to take full advantage of the diagnostic information that is available for each school's unique circumstances. Decisions of reallocation of resources (which may also require further inquiry beyond DEA) must be made in the context of careful consideration of consequences for each member school in a district.

Implications

Taken together, the conclusions drawn from this study have implications for collaborative school improvement, for managerial techniques in education, and for further research utilizing DEA techniques.

Implications for School-University Partnerships

Implications concerning collaborative efforts for school improvement flow naturally from DEA analysis. Effective use of DEA results depend upon shared strategies for school improvement, as well as upon shared sources of input and output data.

School and university partnerships which are formed for the purpose of collaborative research for school improvement and for the preparation of teachers and educational administrators are a logical place for DEA research to be effectively applied. Western Massachusetts is fortunate to have such a network of schools and exemplary educators already in place. The Coalition for School Improvement is a partnership of thirty-five public elementary and secondary schools and the University of Massachusetts at Amherst which is dedicated to creating equal and quality education for all students. Within this type of support system, DEA analysis could be applied in an annual assessment. Member schools could cooperatively define the relevant inputs and outputs and mutually share in efforts to develop better methods of application.

Implications for Managerial Techniques

DEA also holds implications for management techniques at the school and district levels. For example, school principals may effectively submit valid operational plans utilizing DEA results (perhaps annually) in which school goals for achievement and efficiency are specified and needed resources are requested. District administrators may use DEA analysis as "audit" information to review plans for approval or to balance scarce resources among schools. School and district administrators may both value and use an objective measure of their success when evaluating whether goals have been realistically formed and met (Bessent et al. 1982). Finally, as in Bessent, Bessent, Charnes, Cooper and Thorogood (1983), proposed programs may be evaluated using DEA before they are implemented, thus helping to produce successful outcomes.

Implications for Further Research

Implications for further research include extending DEA application to middle and secondary schools and/or to a statewide population of schools. Additionally, results may be aggregated at different levels of analysis. Where DEA is applied to data for individual students, we can help students make better use of their resources for learning (Bessent et al. 1982). This information can be aggregated at the classroom level to help teachers recognize ways to produce learning environments that are tailored to their students' needs. For school planning at the building level, DEA results for all grade levels aggregated by classrooms will provide principals with detailed information for managerial decision making.

Window analysis applies DEA to a group of schools at specified intervals over specified periods of time. For example, a district which seeks to use its resources optimally for each member school might plan to apply DEA annually over a five year period. Member schools would then be able to chart their progress over time both individually and in relation to other schools in the district. This technique should be quite valuable in evaluating long-term educational programs and goals. In Massachusetts, limitations exist presently in the availability of data for inputs and outputs since the Massachusetts Educational Assessment Program tests are administered biennially.

Closing

DEA is a beginning -- an important beginning -- in the process of inquiry into how individual schools can improve their learning environments. All recommendations presented here should be viewed in this context of providing potential direction and serving as catalysts for further evaluation of individual schools. In this context, we must remember that <u>people</u> are of paramount importance where schools are concerned. Studies of technical efficiency in the use of educational resources exist to help in creating optimal learning experiences for students. Where optimal use of scarce resources is not recognized as a priority for student learning, DEA may not be effectively utilized. Employed by teams of dedicated and highly motivated educators, however, DEA can add significantly to renewal at the school level by providing school decision makers with the tools to make valuable and effective choices.

APPENDIX A

SUMMARY OF SIGNIFICANT INPUT MEASURES DETERMINED IN INPUT - OUTPUT STUDIES

SUMMARY OF SIGNIFICANT INPUT MEASURES DETERMINED IN INPUT - OUTPUT STUDIES

Input* Study	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mollenkopft and Melville	1956	+	+	+	+	+										
Goodman	1959			+			+	+								
Thomas	1962	+			+		+	+	+							+
Beson	1965							+	+							
Coleman	1966															
Burkhead, Fox and Holland	1967	+	+				+	+								
Cohn	1968							+							−	
Hanushek	1968						+			+	−	+	+			
Levin	1968						+			+						
Katzman	1968					−	±									
Raymond	1968							+								
Bowles	1969									+					+	

Study / Input*	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fox	1969		+													
Kiesling	1969		-			-										
Hanushek	1970									+						
Kiesling	1970		+				+						-			
Levin	1970						+									
Michelson	1970						+			+		+	+			
Kiesling	1971															
Guthrie	1971						+			+						
Averch and Keisling	1972			-				+					+	+		
Brown	1972												+	+		
Perl	1973		+					+					+			
Bidwell and Kasarda	1975					+								-	+	
Cohn, Millman and Chew	1975							+								

Study / Input*	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Murnane	1975		+													
Sledge	1975					+						+				
Winkler	1975		+					+								
Brown	1976		+													
Summers and Wolfe	1977		+		+		+									
Dunkelberger and Soderberg	1980		+			+										
Freeman and Hatley	1981															
Sebold and Dato	1981		+													
Wendling and Cohn	1981		+		+	+					+				+	
Summers and Reaivets	1982						+									
Guth	1983						+								+	
Webb, Metos, and Metha	1984					+	+	+								

Study / Input*	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Turner, Camilli, Kroc, and Hoover	1986							+							+	
Eberts and Stone	1988															

*Inputs:

1 - Number of books in library
2 - School expenditures
3 - School support personnel
4 - Class size
5 - Student/Teacher ratio
6 - Teacher experience
7 - Teacher salary
8 - Family income
9 - Teacher verbal ability
10 - Geographic location
11 - Possession in home
12 - Parent education
13 - Socio-economic status
14 - Teacher education
15 - Student attendance
(+) - Positive significant relationship
(-) - Negative significant relationship

APPENDIX B

SCHOOLS PARTICIPATING IN THE STUDY

SCHOOLS PARTICIPATING IN THE STUDY

The following list of participating schools is arranged alphabetically. A random number has been assigned to each school for use in the study.

Alice Beal Elementary School
Allendale Elementary School
Atalmadge Elementary School
Barry Elementary School
Belcher Elementary School
Belmont Street Elementary School
Benjamin J. Phelps Elementary School
Blueberry Hill Elementary School
Bonsville Elementary School
Bridge Street Elementary School
Burncoat Street Elementary School
Canterbury Street Magnet School
Chandler Elementary Community School
Chapin Street Elementary School
Clark Street Elementary School
Clifford Granger Elementary School
Craneville Elementary School
Daniel Brunton Elementary School
Dartmouth Street Elementary School
East Meadow Elementary School
East Street Elementary School
Elm Park Community Elementary School
Flagg Street Elementary School
Florence Elementary School
Franklin Avenue Elementary School
Gates Lane Elementary School
General John J. Stefanik Elementary School
Glenwood Elementary School
Granite Street Elementary School
Green Meadows Elementary School
Greylock Elementary School
Heard Street Elementary School
Highland Elementary School
Hooker Elementary School
Indian Orchard Elementary School
John Crosby Elementary School
John Fausey Elementary School
Johnson Elementary School
Kensington Avenue Elementary School
Lakeview Elementary School
Lanesborough Elementary School
Lee Elementary School
Lt. C. Sullivan Elementary School
Litwin Elementary School

Mapleshade Elementary School
Memorial Elementary School, Springfield
Memorial Elementary School, West Springfield
Midland Elementary School
Mill Swan Elementary School
Mittineague Elementary School
Morningside Community Elementary School
Mosier Elementary School
Nelson Place Elementary School
New Ludlow Elementary School
Norrback Avenue Elementary School
Parsons Elementary School
Powder Mill Elementary School
Quabaug Elementary School
Quinsigamond Elementary School
Rice Square Elementary School
Robert K. Finn Ryan Road School
Robinson Park Elementary School
Samuel Bowles Elementary School
Soule Road Elementary School
Southampton Road Elementary School
Stearns Elementary School
Sullivan Elementary School
Tatham Elementary School
Thomas Balliet Elementary School
Thorndike Elementary School
Thorndike Street Elementary School
Thorndyke Road Elementary School
Vernon Hill Elementary School
Veterans Park Elementary School
Wawecus Road Elementary School
West Side Community Elementary School
West Tatnuck Elementary School
William A. Cowing Elementary School
Williams Elementary School
Wolf Swamp Road Elementary School
Woodland Street Community Elementary School

APPENDIX C

COVER LETTER
AND QUESTIONNAIRE

Public School Application of Data
Envelopment Analysis

October, 1989

Dear Sir or Madam:

We would appreciate your cooperation in participating in our research for school improvement. It is our hope that our study may be used to better understand the factors that may contribute to student learning. Our study is based on a sample of elementary schools in Western Massachusetts. Results of the study will be sent to you so that you may use our findings in your efforts to improve learning for all students.

The brief questionnaire which is attached will provide part of the information that will be used for the study. It is purposely designed to elicit information that is unique to each elementary school participating.

We respect the fact that you have a busy schedule and professional priorities, hence we ask that you take only a few minutes to answer three straight-forward questions about your school. If you choose not to participate, please return the questionnaire in the self-addressed, stamped envelope in order that we may account for all responses. A response no later than November 30, 1989, will be appreciated.

Of course, all responses will be kept strictly confidential.

We very much appreciate your consideration in taking time to share this important information with us.

Sincerely,

Dr. Robert Sinclair
Professor and Director
Coalition for School Improvement
University of Massachusetts

Reza Zomorrodian
Research Associate
Coalition for School Improvement of
University of Massachusetts

QUESTIONNAIRE

1. How many students and teachers does the school have for each grade listed?

Grade:	1	2	3	4	5	6	7	8
Teachers:	____	____	____	____	____	____	____	____
Students:	____	____	____	____	____	____	____	____

2. Please complete the list below for staff members at the <u>fourth</u> grade level. (A best estimate is acceptable.):

Fourth Grade	Teacher #1	Teacher #2	Teacher #3	Teacher #4	Teacher #5
a) Total Years of Experience	______	______	______	______	______
b) Years of Experience at Current School	______	______	______	______	______
c) Master Degree or higher (Please Check)	______	______	______	______	______
d) Approximate Salary	______	______	______	______	______

3. Do fourth grade students usually have the same teacher for language arts, science, and mathematics instruction?

Yes ____ No ____

APPENDIX D

OUTPUT AND INPUT DATA FOR 81 SCHOOLS PARTICIPATING IN THE STUDY

DMU	OUTPUT VARIABLES Read	Math	Science	Social
1	1,380	1,310	1,360	1,370
2	1,280	1,330	1,330	1,300
3	1,390	1,330	1,300	1,400
4	1,170	1,140	1,210	1,180
5	1,440	1,430	1,420	1,390
6	1,320	1,310	1,320	1,320
7	1,110	1,100	1,110	1,120
8	1,320	1,290	1,300	1,270
9	1,360	1,300	1,320	1,280
10	1,390	1,340	1,350	1,330
11	1,220	1,230	1,190	1,230
12	1,310	1,290	1,270	1,230
13	1,220	1,260	1,230	1,250
14	1,120	1,170	1,130	1,150
15	1,260	1,190	1,160	1,200
16	1,080	1,140	1,050	1,120
17	1,340	1,320	1,350	1,380
18	1,380	1,330	1,310	1,400
19	1,130	1,170	1,190	1,140
20	1,260	1,230	1,260	1,260
21	1,280	1,270	1,280	1,290
22	1,230	1,240	1,230	1,210
23	1,220	1,300	1,250	1,240
24	1,300	1,230	1,270	1,260
25	1,380	1,330	1,380	1,370
26	1,190	1,240	1,220	1,180
27	1,370	1,360	1,350	1,390
28	1,230	1,230	1,230	1,230
29	1,390	1,320	1,320	1,340
30	1,310	1,240	1,280	1,310
31	1,190	1,190	1,220	1,210
32	1,420	1,450	1,430	1,470
33	1,200	1,160	1,200	1,180
34	1,190	1,230	1,200	1,210
35	1,160	1,120	1,120	1,100
36	1,270	1,270	1,340	1,280
37	1,180	1,190	1,140	1,160
38	1,320	1,320	1,260	1,300
39	1,360	1,280	1,360	1,300
40	1,370	1,390	1,350	1,420

	OUTPUT VARIABLES			
DMU	**Read**	**Math**	**Science**	**Social**
41	1,340	1,320	1,260	1,310
42	1,300	1,290	1,300	1,330
43	1,330	1,330	1,340	1,360
44	1,320	1,380	1,340	1,350
45	1,300	1,310	1,320	1,310
46	1,370	1,330	1,340	1,330
47	1,420	1,350	1,370	1,390
48	1,330	1,330	1,350	1,350
49	1,370	1,380	1,330	1,360
50	1,240	1,240	1,250	1,220
51	1,330	1,310	1,330	1,350
52	1,440	1,300	1,340	1,410
53	1,350	1,280	1,280	1,270
54	1,330	1,280	1,340	1,300
55	1,290	1,280	1,290	1,280
56	1,290	1,270	1,320	1,260
57	1,320	1,340	1,340	1,310
58	1,330	1,370	1,420	1,310
59	1,180	1,230	1,250	1,230
60	1,320	1,300	1,310	1,300
61	1,240	1,260	1,280	1,280
62	1,200	1,250	1,240	1,240
63	1,480	1,440	1,390	1,460
64	1,480	1,520	1,450	1,470
65	1,300	1,280	1,320	1,300
66	1,280	1,330	1,390	1,330
67	1,230	1,330	1,300	1,290
68	1,250	1,240	1,270	1,240
69	1,160	1,140	1,190	1,170
70	1,250	1,200	1,210	1,200
71	1,370	1,230	1,300	1,310
72	1,250	1,260	1,260	1,240
73	1,240	1,260	1,240	1,240
74	1,210	1,200	1,230	1,190
75	1,270	1,220	1,230	1,250
76	1,280	1,250	1,290	1,280
77	1,200	1,160	1,160	1,160
78	1,300	1,260	1,440	1,320
79	1,160	1,140	1,130	1,160
80	1,250	1,260	1,260	1,180
81	1,170	1,200	1,260	1,240

	INPUT VARIABLES					
DMU	PRESCHOL	NOFREEL	S.A.I.	NONMIN	T-RATIO	TOTEXP
1	69	89	13.12	100.0	3.45	25.34
2	58	86	11.39	97.7	5.26	19.00
3	76	100	14.33	95.2	4.17	19.00
4	69	39	11.02	95.8	3.85	13.00
5	79	96	11.92	96.2	4.28	28.34
6	80	87	13.57	100.0	4.00	9.50
7	71	41	14.21	76.4	4.48	5.67
8	86	76	13.54	93.6	4.11	20.67
9	69	86	14.28	97.1	4.55	21.00
10	79	83	15.84	96.4	4.62	16.34
11	56	43	13.52	100.0	3.13	13.13
12	69	58	11.93	91.4	3.80	11.00
13	71	57	12.90	89.4	4.49	23.00
14	47	6	10.75	40.5	4.44	3.00
15	57	6	13.18	47.8	3.92	13.00
16	32	6	13.55	40.7	3.41	7.00
17	66	77	12.05	100.0	3.34	23.00
18	90	82	14.14	95.8	5.13	19.00
19	61	57	11.76	92.7	5.26	14.00
20	76	65	14.75	76.5	5.88	9.00
21	70	76	11.97	100.0	3.39	20.00
22	48	49	12.70	77.8	4.76	23.50
23	76	76	13.79	82.4	3.34	20.00
24	60	64	15.20	80.0	3.45	16.00
25	73	87	11.99	89.1	4.48	24.00
26	66	60	10.42	64.0	3.03	7.00
27	86	81	12.02	93.7	4.65	34.50
28	65	70	13.90	93.3	5.26	34.00
29	68	82	15.38	85.7	4.54	5.00
30	54	42	13.35	84.6	5.51	13.00
31	63	66	13.45	96.7	5.88	27.50
32	84	96	14.87	92.2	4.35	22.34
33	67	56	11.01	96.2	3.57	30.00
34	77	39	14.23	62.9	3.70	21.00
35	33	17	11.95	59.5	3.13	15.00
36	78	51	14.70	66.7	5.00	25.00
37	62	10	12.96	55.4	3.95	15.00
38	63	88	13.39	97.1	3.75	15.84
39	52	84	12.20	94.8	3.75	22.67
40	64	95	14.83	97.2	4.65	18.50

	INPUT VARIABLES					
DMU	PRESCHOL	NOFREEL	S.A.I.	NONMIN	T-RATIO	TOTEXP
41	58	64	15.00	100.0	4.48	16.00
42	58	86	11.70	97.6	4.29	19.70
43	57	77	12.12	90.0	4.35	20.00
44	62	63	12.99	82.1	5.00	22.00
45	72	86	13.27	92.5	4.17	18.67
46	76	91	14.26	96.4	4.21	17.00
47	70	91	11.29	98.9	3.96	11.25
48	76	96	12.16	93.9	4.55	18.30
49	79	94	14.55	92.2	4.67	11.07
50	45	50	11.45	95.7	4.05	22.34
51	81	93	12.65	90.5	3.85	29.00
52	69	65	16.13	93.7	3.45	21.00
53	66	100	11.11	94.4	3.70	32.00
54	70	85	11.58	96.3	3.66	24.34
55	70	83	11.76	91.7	4.04	16.60
56	59	84	13.55	100.0	4.00	18.00
57	57	84	14.97	96.0	3.71	19.00
58	66	59	13.45	94.7	4.17	19.00
59	75	85	13.80	100.0	4.17	20.00
60	55	92	11.29	98.1	4.05	23.67
61	39	85	12.21	58.8	4.00	22.50
62	61	91	13.82	95.7	4.00	11.67
63	88	99	13.07	92.0	4.62	24.34
64	96	98	12.48	92.6	4.62	18.67
65	85	100	12.97	86.7	4.55	21.67
66	51	84	13.30	98.4	4.27	21.25
67	49	54	12.71	85.0	6.45	12.50
68	56	64	14.09	75.6	3.39	26.50
69	46	57	13.30	60.7	3.23	21.00
70	48	43	12.99	51.9	3.85	3.67
71	64	66	13.87	90.0	2.78	13.00
72	48	43	14.12	44.7	3.85	18.34
73	57	37	14.41	57.1	3.53	18.00
74	46	19	14.56	20.3	5.97	11.75
75	64	59	14.03	58.0	3.68	19.00
76	48	65	12.72	54.5	4.11	13.67
77	58	44	10.67	69.1	4.35	5.17
78	76	100	12.57	100.0	4.17	23.00
79	42	29	10.75	78.4	5.00	18.00
80	52	48	12.96	83.9	5.45	21.67
81	16	65	11.51	89.1	4.84	21.33

	INPUT VARIABLES				
DMU	CUREXP	DEGREE	SALARY	EXPENDIT	TOTCOST
1	15.34	200	32,333	125.0	4,100
2	16.67	167	29,469	97.5	3,500
3	16.50	150	30,000	125.0	2,900
4	8.00	200	26,667	87.5	3,100
5	24.34	100	30,935	87.5	3,100
6	2.00	150	28,000	87.5	3,100
7	4.67	167	25,667	87.5	3,100
8	7.67	134	32,500	87.5	3,100
9	5.00	200	22,500	87.5	3,100
10	8.67	167	28,333	87.5	3,100
11	11.13	150	25,700	82.5	2,700
12	10.67	100	25,108	82.5	2,700
13	11.25	125	29,913	82.5	2,700
14	2.00	150	19,000	87.5	3,300
15	3.50	150	33,000	87.5	3,300
16	3.67	134	21,667	87.5	3,300
17	4.00	200	30,000	87.5	3,300
18	20.00	150	33,500	87.5	3,300
19	5.50	150	28,500	87.5	3,300
20	2.50	150	21,500	87.7	3,300
21	5.00	200	36,000	87.5	3,300
22	22.00	200	35,000	87.5	3,300
23	3.00	200	36,000	87.5	3,300
24	3.00	100	34,000	87.5	3,300
25	9.70	200	31,333	87.5	3,300
26	3.00	100	26,000	87.5	3,300
27	15.00	200	35,000	87.5	3,300
28	2.50	200	35,000	87.5	3,300
29	3.00	100	24,500	87.5	3,300
30	13.00	150	28,500	87.5	3,300
31	9.50	150	34,000	87.5	3,300
32	3.67	167	32,500	87.5	3,300
33	18.00	200	35,000	87.5	3,300
34	10.00	200	34,000	87.5	3,300
35	4.50	200	30,000	87.5	3,300
36	10.00	200	34,000	87.5	3,300
37	8.34	167	30,334	87.5	3,300
38	5.83	150	28,917	145.0	3,500
39	11.34	134	28,667	185.0	3,500
40	17.00	150	31,450	105.0	3,500

	INPUT VARIABLES				
DMU	CUREXP	DEGREE	SALARY	EXPENDIT	TOTCOST
41	1.67	134	31,000	145.0	3,500
42	14.67	167	28,667	97.5	3,300
43	13.50	100	30,000	97.5	3,300
44	9.00	200	33,000	97.5	3,300
45	17.00	134	34,334	115.0	3,300
46	8.75	100	28,378	70.0	2,500
47	8.00	125	26,334	70.0	2,500
48	11.67	167	30,867	70.0	2,500
49	5.14	157	28,429	87.5	3,500
50	6.00	200	33,362	115.0	3,300
51	5.50	200	31,300	115.0	3,300
52	21.00	200	31,389	115.0	3,300
53	26.00	100	28,306	115.0	3,300
54	15.67	134	29,767	115.0	3,300
55	14.80	160	27,000	60.0	2,900
56	4.00	200	30,000	145.0	2,900
57	19.00	200	32,000	145.0	2,900
58	3.00	200	34,000	145.0	2,900
59	20.00	200	32,000	145.0	2,900
60	14.34	134	29,667	70.0	3,700
61	20.50	150	26,000	70.0	3,700
62	11.34	200	28,000	70.0	3,700
63	13.67	200	34,567	87.5	3,900
64	14.67	134	34,133	87.5	3,900
65	19.67	100	30,000	70.0	3,300
66	9.25	125	28,750	145.0	3,500
67	2.50	150	27,000	145.0	3,500
68	9.50	150	32,400	70.0	2,700
69	18.00	150	32,600	70.0	2,700
70	3.34	100	23,000	70.0	2,700
71	2.00	100	30,000	70.0	2,700
72	10.00	200	34,000	70.0	2,700
73	1.00	200	33,465	70.0	2,700
74	5.75	150	31,000	70.0	2,700
75	12.00	134	33,000	70.0	2,700
76	6.67	100	31,000	70.0	2,700
77	1.67	100	24,000	115.0	3,100
78	23.00	100	29,572	115.0	3,100
79	11.00	100	28,200	115.0	3,100
80	11.00	200	32,334	115.0	3,100
81	10.67	100	30,000	115.0	3,100

APPENDIX E

MATHEMATICAL FORMULATION OF DEA

The mathematical formulation of the DEA is described in this section (Charnes, Cooper, and Rhodes, 1978; Bessent and Bessent, 1980). This model is developed by Charnes, Cooper, and Rhodes (the CCR Model) which explains the output augmentation side and an input reduction side of the model. The CCR input model is presented below:

Suppose that there are n Decision Making Units (DMUs) to be analyzed, each of which uses m inputs to produce s outputs.

Let:

Y_{rj} = measurement of rth value output for decision making unit j; $r = 1, \ldots s$, $j = 1, \ldots n$

X_{ij} = measurement of ith value input for decision making unit j; $i = 1, \ldots m$, $j = 1, \ldots n$

U_{rk} = weight for output r to be calculated from the analysis for unit k.

V_{ik} = weight for input i to be calculated from the analysis for unit k.

h_k = the efficiency value sought for DMU k.

The objective function is the ratio of the total weighted output of DMUK divided by its total weighted input.

$$\text{Maximize} \quad h_k = \frac{\sum_{r=1}^{s} U_{rk} \; Y_{rk}}{\sum_{i=1}^{m} V_{ik} \; X_{ik}}$$

Subject to:

$$\frac{\sum_{r=1}^{s} U_{rk} \; Y_{rj}}{\sum_{i=1}^{m} V_{ik} \; X_{ij}} \leq 1$$

$$j = 1, \ldots, k, \ldots, n$$

$$U_{rk} > 0; \; r = 1, \ldots, s$$

$$V_{ik} > 0; \; i = 1, \ldots, m$$

This ratio model is then transformed into a linear programming model with both primal and dual forms:

Primal model:

$$\text{Maximize} \quad h_k = \sum_{r=1}^{s} U_{rk} \, Y_{rk}$$

Subject to:

$$\sum_{i=1}^{m} V_{ik} \, X_{ik} = 1$$

$$\sum_{r=1}^{s} U_{rk} \, Y_{rj} - \sum_{i=1}^{m} V_{ik} \, X_{ij} \leq 0$$

$j = 1, \ldots, k, \ldots, n$

$- U_{rk} \leq - \epsilon; \; r = 1, \ldots, s$

$- V_{ik} \leq - \epsilon; \; i = 1, \ldots, m$

where $\epsilon > 0$ is a non-Archimedian (infinitesimal) quantity

Dual Model:

$$\text{Minimize} \quad Z_k = \Theta_k - \epsilon \sum_{r=1}^{s} \overset{+}{S}_{rk} - \epsilon \sum_{i=1}^{m} \overset{-}{S}_{ik}$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j Y_{rj} - \overset{+}{S}_{rk} = Y_{rk}$$

$$r = 1, \ldots, s$$

$$\Theta_k X_{ik} - \sum_{j=1}^{n} \lambda_j X_{ij} - \overset{-}{S}_{ik} = 0$$

$$i = 1, \ldots, m$$

$$\lambda_j,\ \overset{+}{S}_{rk},\ \overset{-}{S}_{ik} \geq 0 \quad \text{for all j, r, and i}$$

Where:

Z_k = reciprocal of h_k = $1/h_k$

λ_j = weight for j th DMU calculated from analysis

$\overset{+}{S}_r$ = slack for r th output

$\overset{-}{S}_i$ = slack for i th input

In this study, since we wish to also allow for increasing or decreasing returns to scale, we employ the BCC model (Banker, Charnes, and Cooper, 1984).

Primal model:

$$\text{Maximize} \quad h_k = \sum_{r=1}^{s} U_{rk} Y_{rk} - W_k$$

$$\text{Subject to:} \quad \sum_{i=1}^{m} V_{ik} X_{ik} = 1$$

$$\sum_{r=1}^{s} U_{rk} Y_{rj} - \sum_{i=1}^{m} V_{ik} X_{ij} - W_k \leq 0$$

$j = 1, \ldots, k, \ldots, n$

$- U_{rk} \leq - \epsilon; \; r = 1, \ldots, s$

$- V_{ik} \leq - \epsilon; \; i = 1, \ldots, m$

where $\epsilon > 0$ is a non-Archimedian (infinitesimal) quantity

Dual Model:

$$\text{Minimize} \quad Z_k = \Theta_k - \epsilon \sum_{r=1}^{s} \overset{+}{S}_{rk} - \epsilon \sum_{i=1}^{m} \overset{-}{S}_{ik}$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j Y_{rj} - \overset{+}{S}_{rk} = Y_{rk}$$

$r = 1, \ldots, s$

$$\Theta_k X_{ik} - \sum_{j=1}^{n} \lambda_j X_{ij} - \overset{-}{S}_{ik} = 0$$

$i = 1, \ldots, m$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$\lambda_j, \overset{+}{S}_{rk}, \overset{-}{S}_{ik} \geq 0$ for all j, r, and i

Where:

Z_k = reciprocal of h_k = $1/h_k$

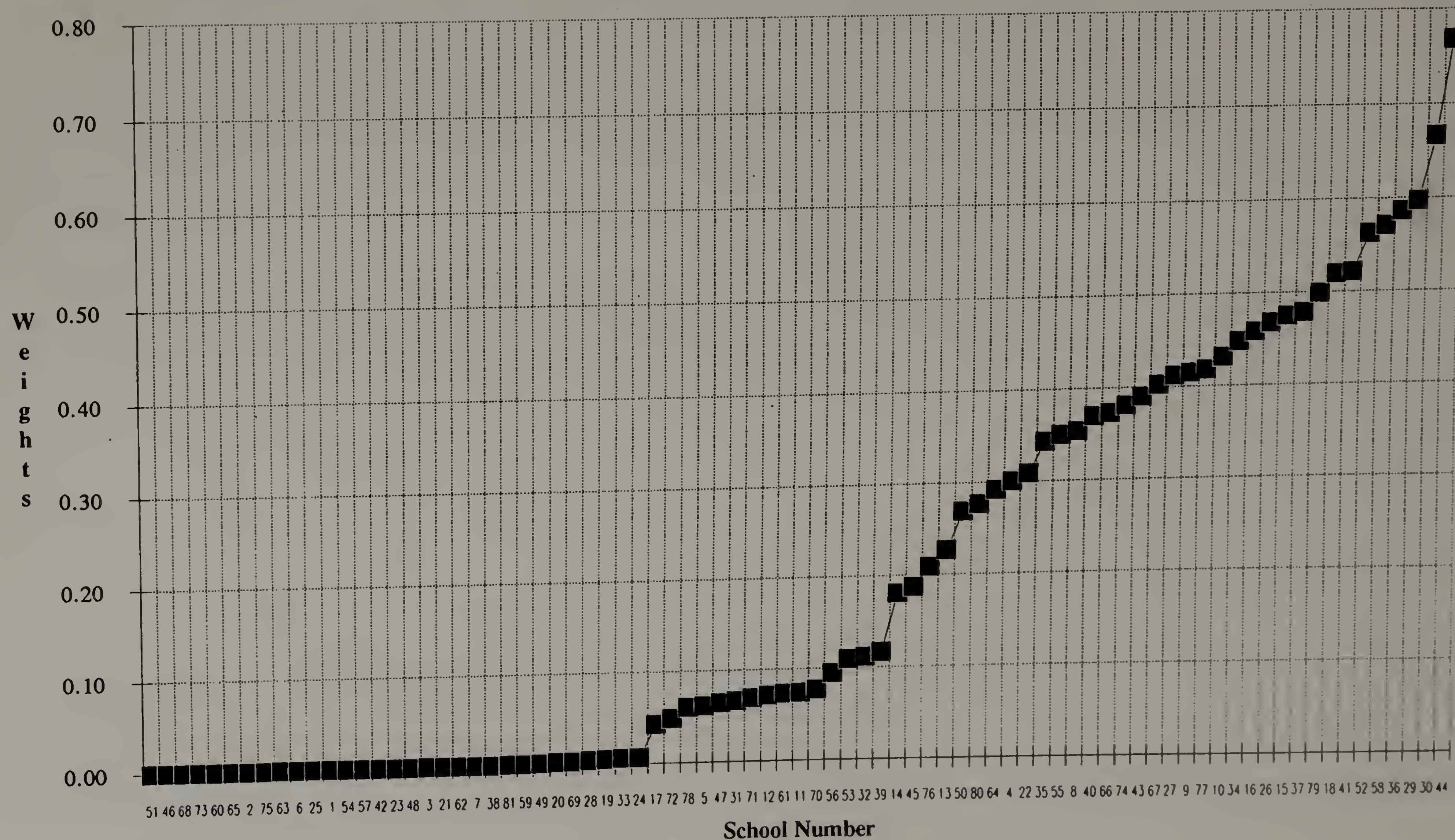
λ_j = weight for j th DMU calculated from analysis

$\overset{+}{S}_r$ = slack for r th output

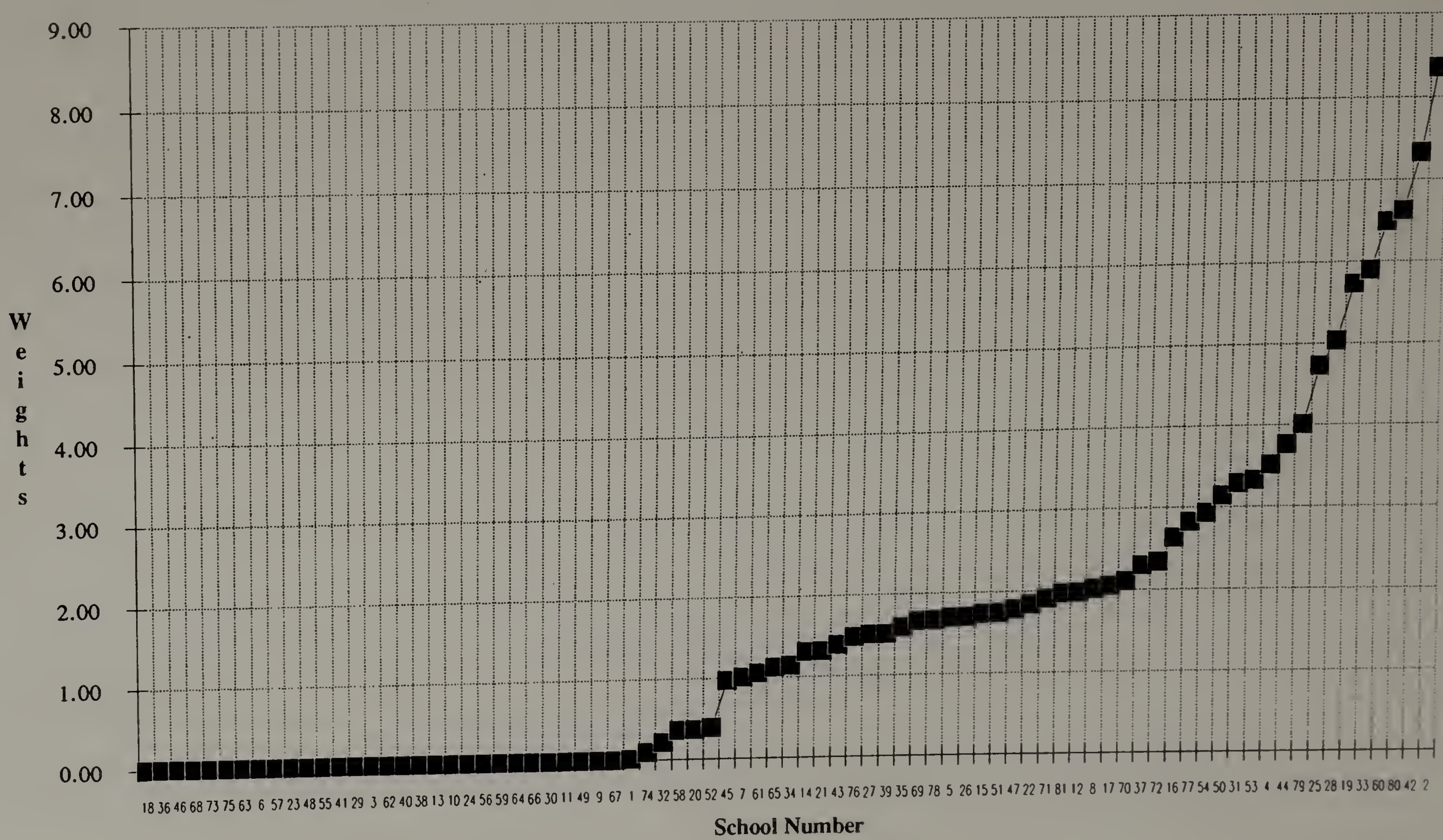
$\overset{-}{S}_i$ = slack for i th input

APPENDIX F

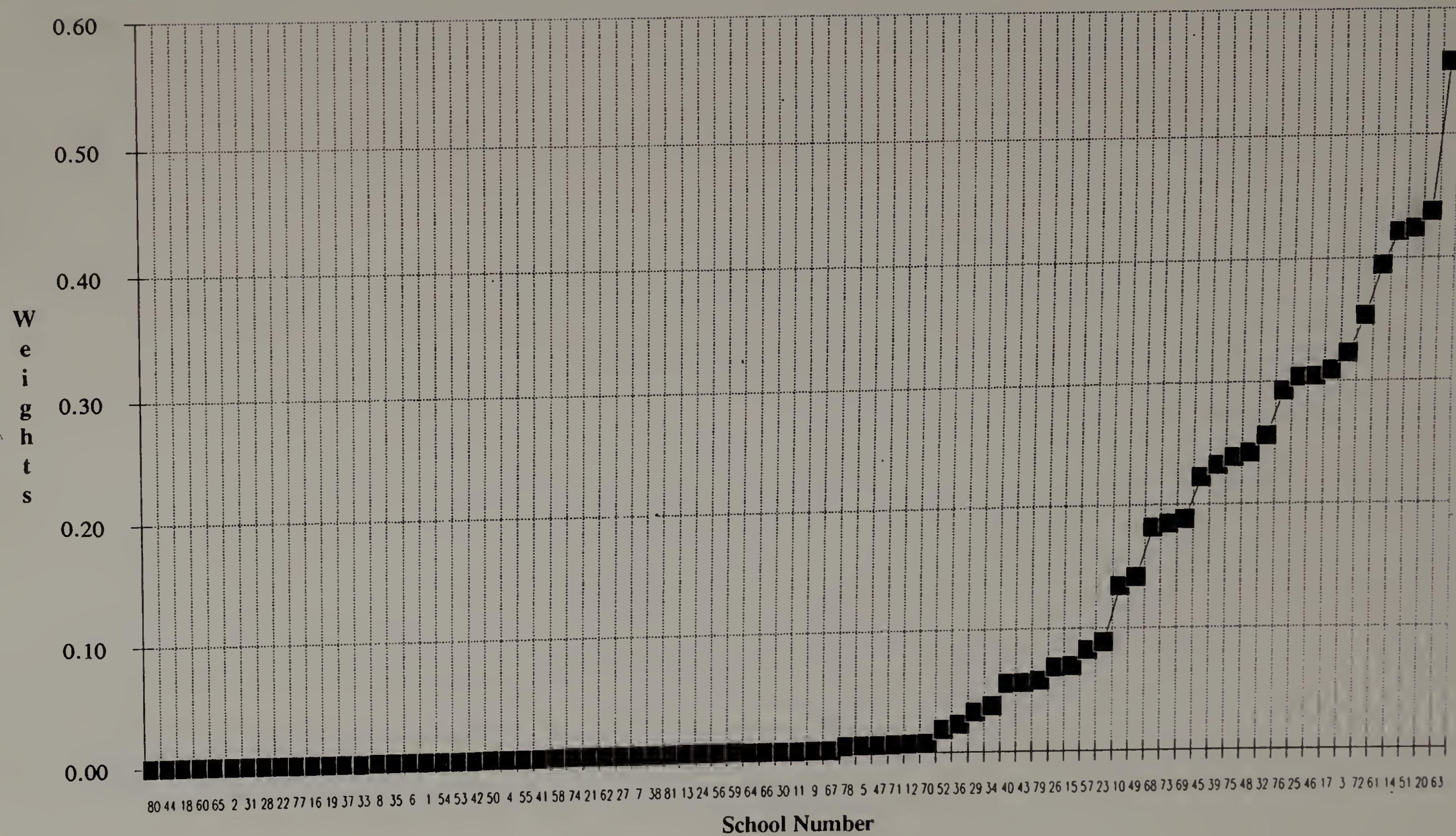
GRAPHICAL REPRESENTATION OF INPUT WEIGHTS
FOR INDIVIDUAL SCHOOLS



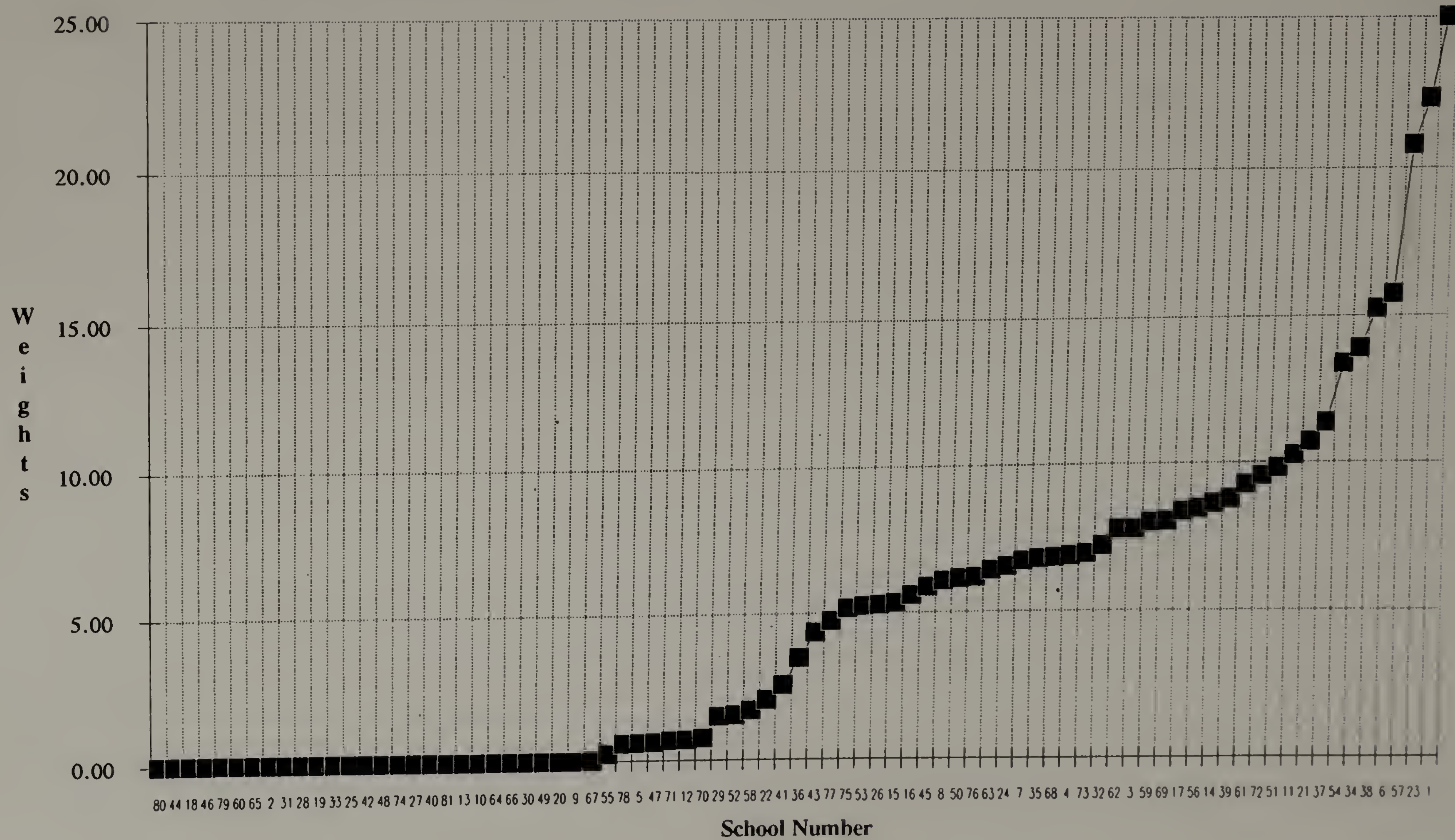
Percentage of Students Not Eligible for Free or Reduced Price Lunch



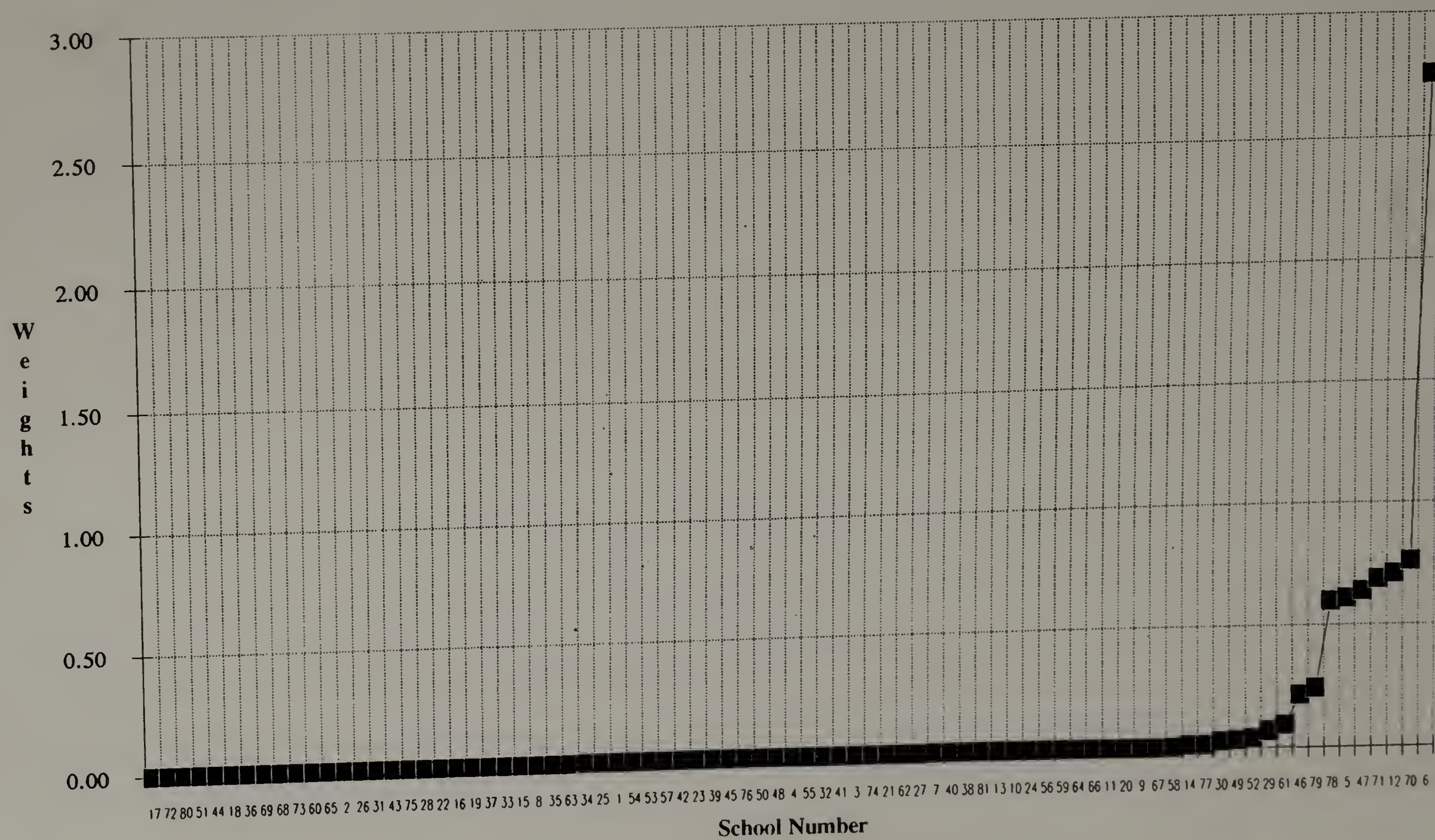
Student Activity Index



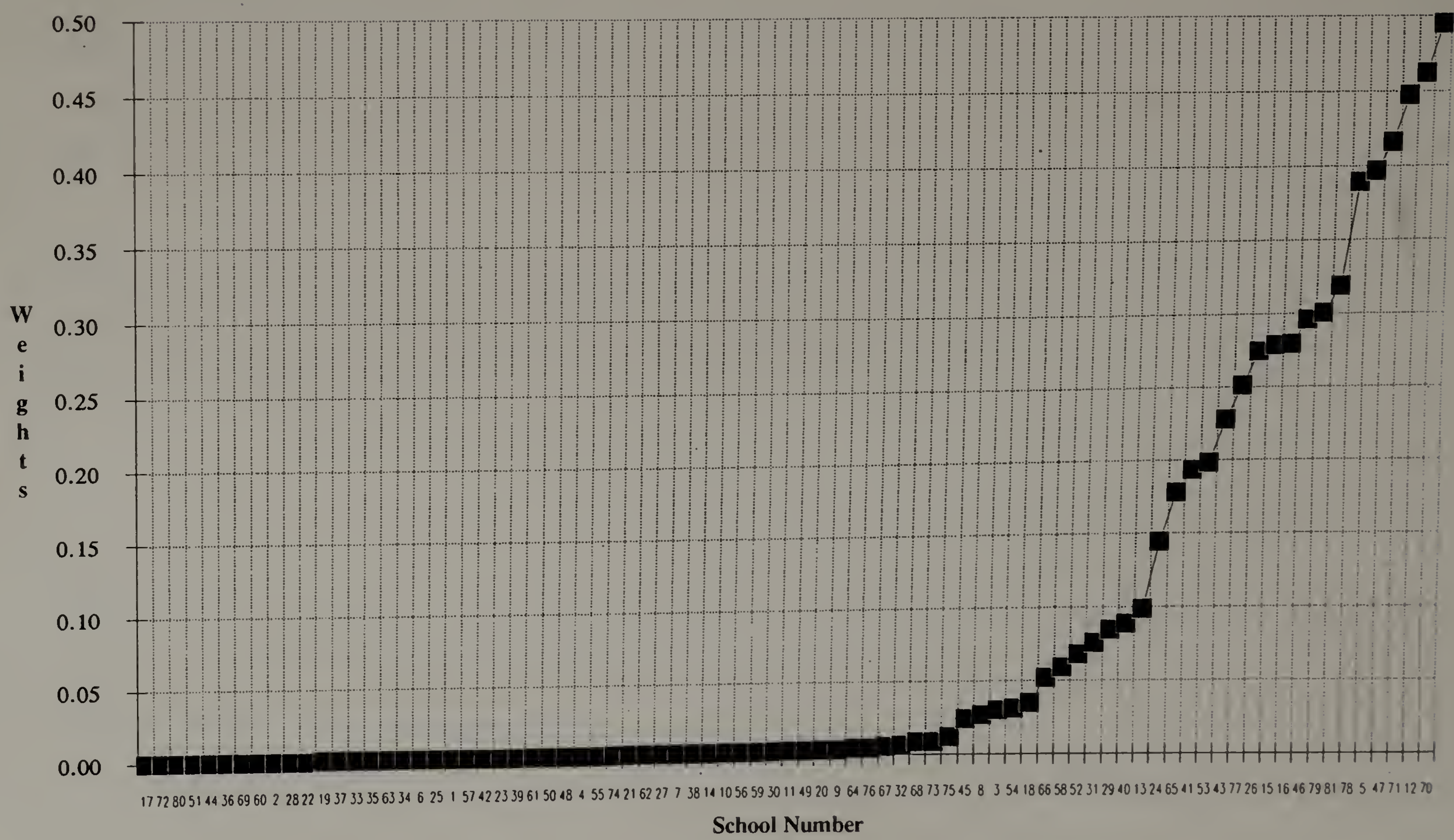
Percentage of Non-Minority Students



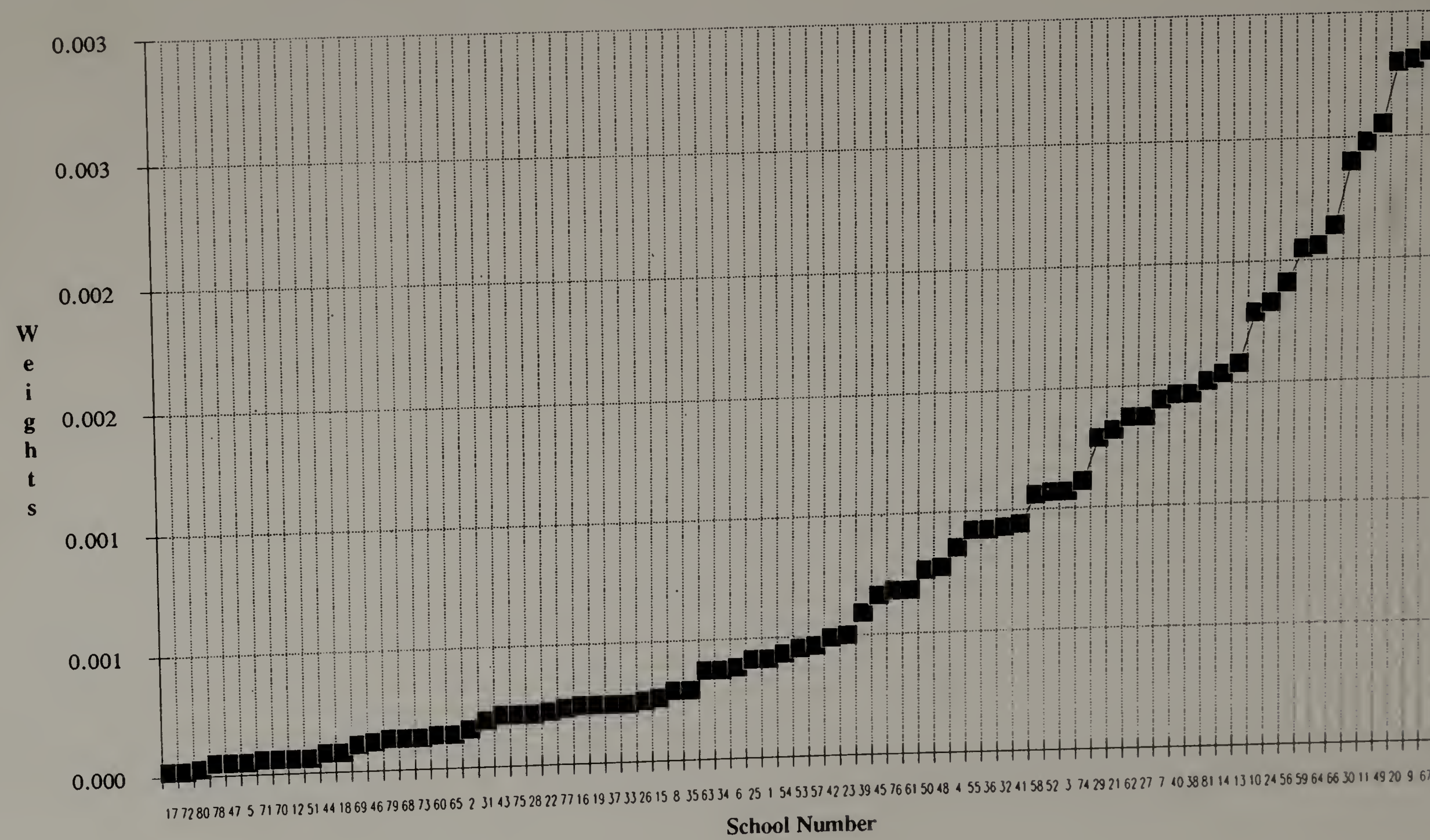
Teacher-Student Ratio



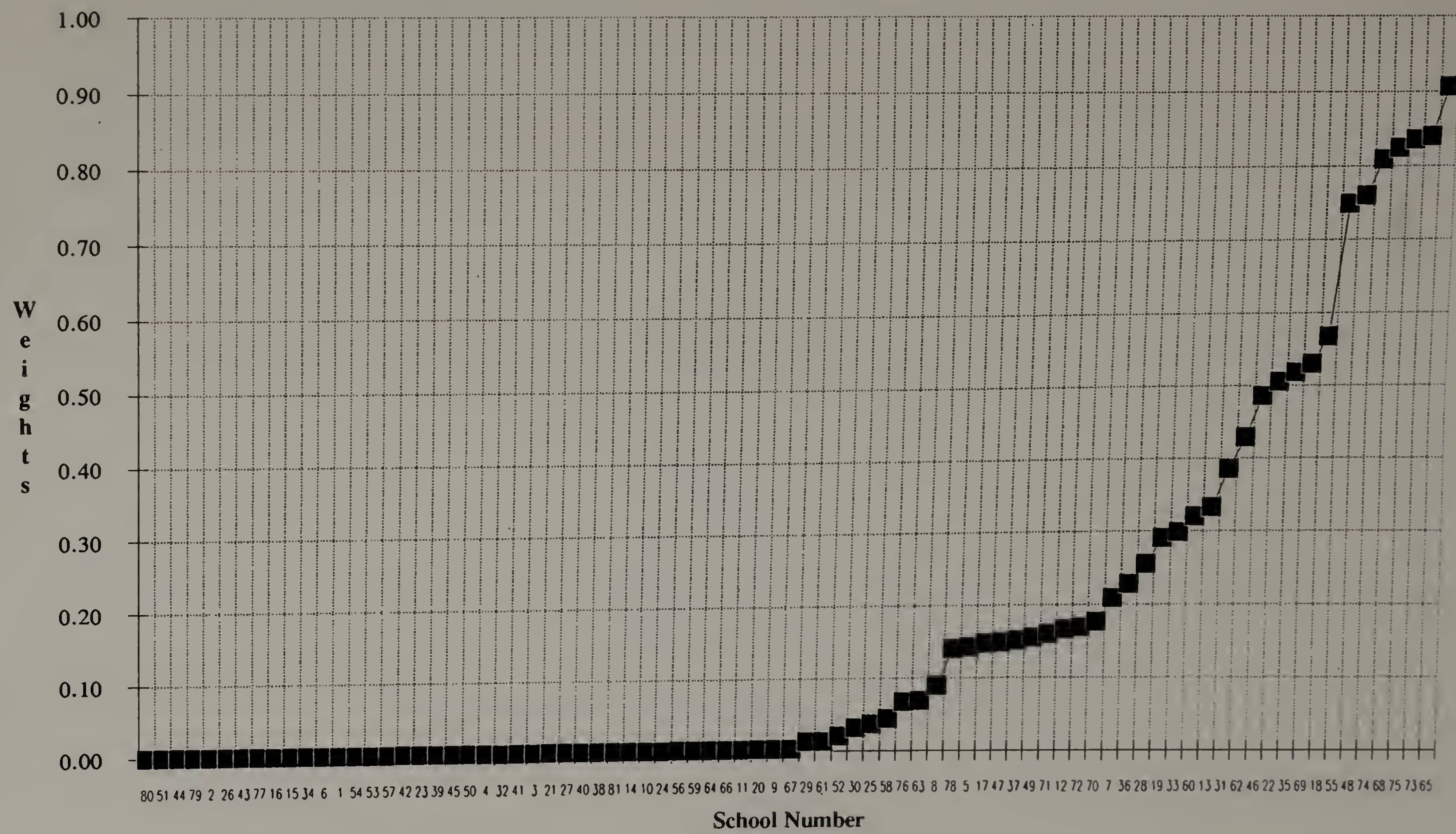
Teachers' Average Total Years of Experience



Teachers' Level of Education



Teachers' Average Salary



Per Student Expenditure on Instructional Materials

APPENDIX G

DEA RESULTS: THETA, IOTA, AND SLACK VALUES

DMU	Theta	Iota	Sum of Slacks
1	1.00000	1.00000	0.00000
2	0.97620	0.97281	2,071.03000
3	0.95925	0.95748	165.32000
4	0.99347	0.96535	3,300.84000
5	1.00000	1.00000	0.00000
6	0.94908	0.94695	557.50000
7	0.86867	0.86316	381.89000
8	0.88272	0.87774	1,691.24000
9	1.00000	1.00000	0.00000
10	0.94946	0.94822	69.04000
11	1.00000	1.00000	0.00000
12	1.00000	1.00000	0.00000
13	0.92615	0.86432	3,922.71000
14	1.00000	1.00000	0.00000
15	1.00000	1.00000	0.00000
16	1.00000	1.00000	0.00000
17	1.00000	1.00000	0.00000
18	0.95136	0.95122	185.69000
19	0.92142	0.91674	1,976.11000
20	1.00000	1.00000	0.00000
21	0.95496	0.86726	6,660.04000
22	0.88657	0.86921	8,047.55000
23	0.98549	0.95403	6,309.23000
24	1.00000	0.86106	7,586.86000
25	0.98184	0.97819	883.29000
26	1.00000	1.00000	0.00000
27	0.98382	0.90909	5,451.55000
28	0.81411	0.80548	4,147.55000
29	1.00000	1.00000	0.00000
30	1.00000	1.00000	0.00000
31	0.85188	0.84358	4,413.90000
32	1.00000	1.00000	0.00000
33	0.96529	0.94292	9,182.19000
34	0.92283	0.91532	2,049.25000
35	1.00000	1.00000	0.00000
36	1.00000	1.00000	0.00000
37	0.98894	0.98866	115.57000
38	0.95245	0.95014	158.59000
39	0.98840	0.98733	182.07000
40	0.94254	0.94066	128.32000

DMU	Theta	Iota	Sum of Slacks
41	0.92052	0.91945	114.40000
42	0.94443	0.93886	1,140.33000
43	1.00000	1.00000	0.00000
44	0.96647	0.96639	103.71000
45	0.87327	0.86513	1,230.11000
46	1.00000	1.00000	0.00000
47	1.00000	1.00000	0.00000
48	0.98260	0.95402	3,693.48000
49	0.96621	0.96285	131.72000
50	0.97051	0.90845	8,154.14000
51	0.94836	0.94830	102.72000
52	1.00000	1.00000	0.00000
53	1.00000	1.00000	0.00000
54	0.98984	0.98137	1,969.70000
55	1.00000	1.00000	0.00000
56	0.89433	0.88870	294.05000
57	0.94490	0.94411	169.31000
58	1.00000	1.00000	0.00000
59	0.80149	0.79739	199.90000
60	0.99933	0.99479	3,185.00000
61	1.00000	1.00000	0.00000
62	0.94239	0.93357	642.69000
63	1.00000	1.00000	0.00000
64	1.00000	1.00000	0.00000
65	1.00000	1.00000	0.00000
66	0.99985	0.99681	141.45000
67	0.98690	0.98260	151.25000
68	0.97944	0.97847	753.65000
69	1.00000	1.00000	0.00000
70	1.00000	1.00000	0.00000
71	1.00000	1.00000	0.00000
72	1.00000	1.00000	0.00000
73	1.00000	1.00000	0.00000
74	1.00000	1.00000	0.00000
75	0.99915	0.99157	3,534.87000
76	1.00000	1.00000	0.00000
77	1.00000	1.00000	0.00000
78	1.00000	1.00000	0.00000
79	1.00000	1.00000	0.00000
80	0.88264	0.88154	4,011.18000
81	1.00000	0.93524	4,300.51000

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